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REPORT

OF THE

SIXTEENTH MEETING

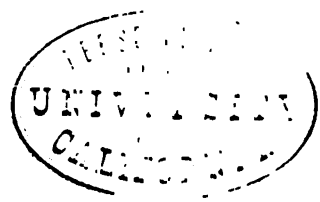
OF THE

BRITISH ASSOCIATION

FOR THE

ADVANCEMENT OF SCIENCE;

HELD AT SOUTHAMPTON IN SEPTEMBER 1846.



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OBJECTS AND RULES

OF

THE ASSOCIATION.

OBJECTS.

The Association contemplates no interference with the ground occupied by other Institutions. Its objects are,—To give a stronger impulse and a more systematic direction to scientific inquiry,—to promote the intercourse of those who cultivate Science in different parts of the British Empire, with one another, and with foreign philosophers,—to obtain a more general attention to the objects of Science, and a removal of any disadvantages of a public kind which impede its progress.

RULES.

ADMISSION OF MEMBERS AND ASSOCIATES.

All Persons who have attended the first Meeting shall be entitled to become Members of the Association, upon subscribing an obligation to conform to its Rules.

The Fellows and Members of Chartered Literary and Philosophical Societies publishing Transactions, in the British Empire, shall be entitled, in like manner, to become Members of the Association.

The Officers and Members of the Councils, or Managing Committees, of Philosophical Institutions, shall be entitled, in like manner, to become Members of the Association.

All Members of a Philosophical Institution recommended by its Council or Managing Committee, shall be entitled, in like manner, to become Members of the Association.

Persons not belonging to such Institutions shall be elected by the General Committee or Council, to become Life Members of the Association, Annual Subscribers, or Associates for the year, subject to the approval of a General Meeting.

COMPOSITIONS, SUBSCRIPTIONS, AND PRIVILEGES.

Life Members shall pay, on admission, the sum of Ten Pounds. They shall receive *gratuitously* the Reports of the Association which may be published after the date of such payment. They are eligible to all the offices of the Association.

Annual Subscribers shall pay, on admission, the sum of Two Pounds, and in each following year the sum of One Pound. They shall receive *gratuitously* the Reports of the Association for the year of their admission and for the years in which they continue to pay *without intermission* their Annual Subscription. By omitting to pay this Subscription in any particular year, Members of this class (Annual Subscribers) *lose for that and all future years* the privilege of receiving the volumes of the Association *gratis*:

but they may resume their Membership and other privileges at any subsequent Meeting of the Association, paying on each such occasion the sum of One Pound. They are eligible to all the Offices of the Association.

Associates for the year shall pay on admission the sum of One Pound. They shall not receive *gratuitously* the Reports of the Association, nor be eligible to serve on Committees, or to hold any office.

The Association consists of the following classes :—

1. Life Members admitted from 1831 to 1845 inclusive, who have paid on admission Five Pounds as a composition.
2. Life Members who in 1846, or in subsequent years, have paid on admission Ten Pounds as a composition.
3. Annual Members admitted from 1831 to 1839 inclusive, subject to the payment of One Pound annually, [may resume their Membership after intermission of Annual Payment.]
4. Annual Members admitted or to be admitted in any year since 1839, subject to the payment of Two Pounds for the first year, and One Pound in each following year, [may resume their membership after intermission of Annual Payment.]
5. Associates for the year, subject to the payment of One Pound.
6. Corresponding Members nominated by the Council.

And the Members and Associates will be entitled to receive the annual volume of Reports, *gratis*, or to *purchase* it at reduced (or Members') price, according to the following specification, viz. :—

1. *Gratis.*—Old Life Members who have paid Five Pounds as a composition for Annual Payments, and Two Pounds as a Book Subscription.

   New Life Members who shall have paid Ten Pounds as a composition.

   Annual Members who have not intermitted their Annual Subscription.
2. *At reduced or Members' Prices.*—Old Life Members who have paid Five Pounds as a composition for Annual Payments, but no Book Subscription.

   Annual Members, who, having paid on admission Two Pounds, have intermitted their Annual Subscription in any subsequent year.

   Associates for the year. [Privilege confined to the volume for that year only.]

Subscriptions shall be received by the Treasurer or Secretaries.

MEETINGS.

The Association shall meet annually, for one week, or longer. The place of each Meeting shall be appointed by the General Committee at the previous Meeting; and the Arrangements for it shall be entrusted to the Officers of the Association.

GENERAL COMMITTEE.

The General Committee shall sit during the week of the Meeting, or longer, to transact the business of the Association. It shall consist of the following persons :—

1. Presidents and Officers for the present and preceding years, with authors of Reports in the Transactions of the Association.
2. Members who have communicated any Paper to a Philosophical Society, which has been printed in its Transactions, and which relates to such subjects as are taken into consideration at the Sectional Meetings of the Association.
3. Office-bearers for the time being, or Delegates, altogether not exceeding three in number, from [illegible]hical Society publishing Transactions.

4. Office-bearers for the time being, or Delegates, not exceeding three, from Philosophical Institutions established in the place of Meeting, or in any place where the Association has formerly met.

5. Foreigners and other individuals whose assistance is desired, and who are specially nominated in writing for the meeting of the year by the President and General Secretaries.

6. The Presidents, Vice-Presidents, and Secretaries of the Sections are *ex officio* members of the General Committee for the time being.

SECTIONAL COMMITTEES.

The General Committee shall appoint, at each Meeting, Committees, consisting severally of the Members most conversant with the several branches of Science, to advise together for the advancement thereof.

The Committees shall report what subjects of investigation they would particularly recommend to be prosecuted during the ensuing year, and brought under consideration at the next Meeting.

The Committees shall recommend Reports on the state and progress of particular Sciences, to be drawn up from time to time by competent persons, for the information of the Annual Meetings.

COMMITTEE OF RECOMMENDATIONS.

The General Committee shall appoint at each Meeting a Committee, which shall receive and consider the Recommendations of the Sectional Committees, and report to the General Committee the measures which they would advise to be adopted for the advancement of Science.

All Recommendations of Grants of Money, Requests for Special Researches, and Reports on Scientific Subjects, shall be submitted to the Committee of Recommendations, and not taken into consideration by the General Committee, unless previously recommended by the Committee of Recommendations.

LOCAL COMMITTEES.

Local Committees shall be formed by the Officers of the Association to assist in making arrangements for the Meetings.

Local Committees shall have the power of adding to their numbers those Members of the Association whose assistance they may desire.

OFFICERS.

A President, two or more Vice-Presidents, one or more Secretaries, and a Treasurer, shall be annually appointed by the General Committee.

COUNCIL.

In the intervals of the Meetings, the affairs of the Association shall be managed by a Council appointed by the General Committee. The Council may also assemble for the despatch of business during the week of the Meeting.

PAPERS AND COMMUNICATIONS.

The Author of any paper or communication shall be at liberty to reserve his right of property therein.

ACCOUNTS.

The Accounts of the Association shall be audited annually, by Auditors appointed by the Meeting.

I. Table showing the Places and Times of Meeting of the British Association, with Presidents, Vice-Presidents, and Local Secretaries, from its Commencement.

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
The EARL FITZWILLIAM, D.C.L., F.R.S., F.G.S., &c. ..... York, September 27, 1831.	Rev. W. Vernon Harcourt, M.A., F.R.S., F.G.S.	William Gray, jun., F.G.S. Professor Phillips, F.R.S., F.G.S.
The REV. W. BUCKLAND, D.D., F.R.S., F.G.S., &c. ..... Oxford, June 19, 1832.	Sir David Brewster, F.R.SS.L. & E., &c. Rev. W. Whewell, F.R.S., Pres. Geol. Soc.	Professor Daubeny, M.D., F.R.S., &c. Rev. Professor Powell, M.A., F.R.S., &c.
The REV. ADAM SEDGWICK, M.A., V.P.R.S., V.P.G.S. ..... Cambridge, June 25, 1833.	G. B. Airy, F.R.S., Astronomer Royal, &c. John Dalton, D.C.L., F.R.S.	Rev. Professor Henslow, M.A., F.L.S., F.G.S. Rev. W. Whewell, F.R.S.
Sir T. MACDOUGAL BRISBANE, K.C.B., D.C.L., F.R.SS. L. & E..... Edinburgh, September 8, 1834.	Sir David Brewster, F.R.S., &c. Rev. T. R. Robinson, D.D.	Professor Forbes, F.R.S., L. & E., &c. Sir John Robison, Sec. R.S.E.
The REV. PROVOST LLOYD, LL.D. ..... Dublin, August 10, 1835.	Viscount Oxmantown, F.R.S., F.R.A.S. ..... Rev. W. Whewell, F.R.S., &c.	Sir W. R. Hamilton, Astron. Royal of Ireland, &c. Rev. Professor Lloyd, F.R.S.
The MARQUIS OF LANSDOWNE, D.C.L., F.R.S., &c. ..... Bristol, August 22, 1836.	The Marquis of Northampton, F.R.S. Rev. W. D. Conybeare, F.R.S., F.G.S. J. C. Prichard, M.D., F.R.S.	Professor Daubeny, M.D., F.R.S., &c. V. F. Hovenden.
The EARL OF BURLINGTON, F.R.S., F.G.S., Chan. Univ. London... Liverpool, September 11, 1837.	The Bishop of Norwich, P.L.S., F.G.S. John Dalton, D.C.L., F.R.S. Sir Philip Grey Egerton, Bart., F.R.S., F.G.S. Rev. W. Whewell, F.R.S.	Professor Traill, M.D. Wm. Wallace Currie, Esq. Joseph N. Walker, Pres. Royal Institution, Liverpool.
The DUKE OF NORTHUMBERLAND, F.R.S., F.G.S., &c. ..... Newcastle-on-Tyne, August 20, 1838.	The Bishop of Durham, F.R.S., F.S.A. The Rev. W. Vernon Harcourt, F.R.S., &c. Prideaux John Selby, Esq., F.R.S.E.	John Adamson, F.L.S., &c. Wm. Hutton, F.G.S. Professor Johnston, M.A., F.R.S.
The REV. W. VERNON HARCOURT, M.A., F.R.S., &c. ..... Birmingham, August 26, 1839.	Marquis of Northampton. Earl of Dartmouth.... The Rev. T. R. Robinson, D.D. ..... John Corrie, Esq., F.R.S. Very Rev. Principal Macfarlane	George Barker, Esq., F.R.S. Peyton Blakiston, M.D. Joseph Hodgson, Esq., F.R.S. Follett Osler, Esq.
The MOST NOBLE THE MARQUIS OF BREADALBANE. ..... Glasgow, September 17, 1840.	Major-General Lord Greenock, F.R.S.E. Sir David Brewster, F.R.S. Sir T. M. Brisbane, Bart., F.R.S. The Earl of Mount Edgecumbe	Andrew Liddell, Esq. Rev. J. P. Nicol, LL.D. John Strang, Esq.

I. Table showing the Places and Times of Meeting of the British Association, &c. (*continued*).

PRESIDENTS.	VICE-PRESIDENTS.	LOCAL SECRETARIES.
The REV. PROFESSOR WHEWELL, F.R.S., &c. PLYMOUTH, July 29, 1841.	The Earl of Morley. Lord Eliot, M.P. Sir C. Lemon, Bart. Sir T. D. Acland, Bart.	W. Snow Harris, Esq., F.R.S. Col. Hamilton Smith, F.L.S. Robert Were Fox, Esq. Richard Taylor, jun., Esq.
LORD FRANCIS EGERTON, F.G.S. MANCHESTER, June 23, 1842.	John Dalton, D.C.L., F.R.S. Hon. and Rev. W. Herbert, F.L.S., &c. Rev. A. Sedgwick, M.A., F.R.S. W. C. Henry, M.D., F.R.S. Sir Benjamin Heywood, Bart.	Peter Clare, Esq., F.R.A.S. W. Fleming, M.D. James Heywood, Esq., F.R.S.
The EARL OF ROSSE, F.R.S. CORK, August 17, 1843.	Earl of Listowel. Viscount Adare Sir W. R. Hamilton, Pres. R.I.A. Rev. T. R. Robinson, D.D.	Professor John Stevelly, M.A. Rev. Jos. Carson, F.T.C. Dublin. Wm. Kelcher, Esq. Wm. Clear, Esq.
The REV. G. PEACOCK, D.D. (Dean of Ely), F.R.S. YORK, September 26, 1844.	Earl Fitzwilliam, F.R.S. Viscount Morpeth, F.G.S. The Hon. John Stuart Wortley, M.P. Sir David Brewster, K.H., F.R.S. Michael Faraday, Esq., D.C.L., F.R.S. Rev. W. V. Harcourt, F.R.S.	William Hatfeild, Esq., F.G.S. Thomas Meynell, Esq., F.L.S. Rev. W. Scoresby, LL.D., F.R.S. William West, Esq.
SIR JOHN F. W. HERSCHEL, Bart., F.R.S., &c. CAMBRIDGE, June 19, 1845.	The Earl of Hardwicke. The Bishop of Norwich. Rev. J. Graham, D.D. Rev. G. Ainslie, D.D. G. B. Airy, Esq., M.A., D.C.L., F.R.S. The Rev. Professor Sedgwick, M.A., F.R.S.	William Hopkins, Esq., M.A., F.R.S. Professor Ansted, M.A., F.R.S.
SIR RODERICK IMPEY MURCHISON, G.C.S., F.R.S. SOUTHAMPTON, September 10, 1846.	The Marquis of Winchester The Earl of Yarborough, D.C.L. Lord Ashburton, D.C.L. Viscount Palmerston, M.P. Right Hon. Charles Shaw Lefevre, M.P. Sir George T. Staunton, Bart., M.P., D.C.L., F.R.S. The Bishop of Oxford, F.R.S. Prof. Owen, M.D., F.R.S. Prof. Powell, F.R.S.	Henry Clark, M.D. T. H. C. Moody, Esq.
SIR ROBERT HARRY INGLIS, Bart., D.C.L., F.R.S., M.P. for the University of Oxford. OXFORD, June 23, 1847.	The Earl of Rosse, F.R.S. The Lord Bishop of Oxford, F.R.S. The Vice-Chancellor of the University. Thomas G. Bucknall Estcourt, Esq., D.C.L., M.P. for the University of Oxford The Very Rev. The Dean of Westminster, D.D., F.R.S. Professor Daubeny, M.D., F.R.S. The Rev. Professor Powell, M.A., F.R.S.	Rev. Robert Walker, M.A., F.R.S. Henry Wentworth Acland, Esq., B.M.

II. Table showing the Names of Members of the British Association who have served on the Council in former years.

Acland, Sir Thomas D., Bart., M.P., F.R.S.
Adamson, J., F.L.S.
Adare. Viscount, M.P., F.R.S.
Airy, G. B., D.C.L., F.R.S., Astronomer Royal.
Ainslie, Rev. Gilbert, D.D., Master of Pembroke Hall, Cambridge.
Ansted, Professor D. T., M.A., F.R.S.
Arnott, Neil, M.D., F.R.S.
Ashburton, Lord, D.C.L.
Babbage, Charles, F.R.S.
Babington, C. C., F.L.S.
Baily, Francis, F.R.S.
Barker, George, F.R.S.
Bengough, George.
Bentham, George, F.L.S.
Bigge, Charles.
Blakiston, Peyton, M.D., F.R.S.
Brewster, Sir David, K.H., LL.D., F.R.S.
Breadalbane, The Marquis of, F.R.S.
Brisbane, Lieut.-General Sir Thomas M., Bart., K.C.B., G.C.H., D.C.L., F.R.S.
Brown, Robert, D.C.L., F.R.S.
Brunel, Sir M. I., F.R.S.
Buckland, Very Rev. William, D.D., Dean of Westminster, F.R.S.
Burlington, The Earl of, M.A., F.R.S., Chancellor of the University of London.
Carson, Rev. Joseph.
Cathcart, The Earl, K.C.B., F.R.S.E.
Chalmers, Rev. T., D.D., Professor of Divinity, Edinburgh.
Christie, Professor S. H., M.A., Sec.R.S.
Clare, Peter, F.R.A.S.
Clark, Rev. Professor, M.D., F.R.S. (Cambridge).
Clark, Henry, M.D.
Clark, G. T.
Clift, William, F.R.S.
Colquhoun, J. C., M.P.
Conybeare, Very Rev. W. D., Dean of Llandaff, M.A., F.R.S.
Corrie, John, F.R.S.
Currie, William Wallace.
Dalton, John, D.C.L., F.R.S.
Daniell, Professor J. F., F.R.S.
Dartmouth, The Earl of, D.C.L., F.R.S.
Daubeny, Professor Charles G.B., M.D., F.R.S.
De la Beche, Sir Henry T., F.R.S., Director-General of the Geological Survey of the United Kingdom.
Drinkwater, J. E.
Durham, The Bishop of, F.R.S.
Egerton, Sir Philip de M. Grey, Bart., F.R.S.
Eliot, Lord, M.P.
Ellesmere, The Earl of, F.G.S.
Faraday, Professor, D.C.L., F.R.S.
Fitzwilliam, The Earl, D.C.L., F.R.S.
Fleming, H., M.D.
Forbes, Charles.
Forbes, Professor Edward, F.R.S.
Forbes, Professor J. D., F.R.S.
Fox, Robert Were, F.R.S.
Gilbert, Davies, D.C.L., F.R.S.
Graham, Rev. John, D.D., Master of Christ's College, Cambridge.
Graham, Professor Thomas, M.A., F.R.S.
Gray, John E., F.R.S.
Gray, Jonathan.
Gray, William, jun., F.G.S.
Green, Professor Joseph Henry, F.R.S.
Greenough, G. B., F.R.S.
Hallam, Henry, M.A., F.R.S.
Hamilton, W. J., M.P., Sec.G.S.
Hamilton, Sir William R., Astronomer Royal of Ireland, M.R.I.A.
Harcourt, Rev. William Vernon, M.A., F.R.S.
Hardwicke, The Earl of.
Harford, J. S., D.C.L., F.R.S.
Harris, W. Snow, F.R.S.
Hatfeild, William, F.G.S.
Henslow, Rev. Professor, M.A., F.L.S.
Henry, W. C., M.D., F.R.S.
Herbert, Hon. and Very Rev. William, Dean of Manchester, LL.D., F.L.S.
Herschel, Sir John F. W., Bart., D.C.L., F.R.S.
Heywood, Sir Benjamin, Bart., F.R.S.
Heywood, James, F.R.S.
Hodgkin, Thomas, M.D.
Hodgkinson, Eaton, F.R.S.
Hodgson, Joseph, F.R.S.
Hooker, Sir William J., LL.D., F.R.S.
Hope, Rev. F. W., M.A., F.R.S.
Hopkins, William, M.A., F.R.S.
Horner, Leonard, F.R.S., F.G.S.
Hovenden, V. F., M.A.
Hutton, Robert, F.G.S.
Hutton, William, F.G.S.
Jameson, Professor R., F.R.S.
Jenyns, Rev. Leonard, F.L.S.
Jerrard, H. B.
Johnston, Professor J. F. W., M.A., F.R.S.
Keleher, William.
Lardner, Rev. Dr.
Lee, R., M.D., F.R.S.
Lansdowne, The Marquis of, D.C.L., F.R.S.
Lefevre, Right Hon. Charles Shaw, Speaker of the House of Commons.
Lemon, Sir Charles, Bart., M.P., F.R.S.
Liddell, Andrew.
Lindley, Professor, Ph.D., F.R.S.
Listowel, The Earl of.
Lloyd, Rev. Bartholomew, D.D., Provost of Trinity College, Dublin.
Lloyd, Rev. Professor, D.D., F.R.S.
Lubbock, Sir John W., Bart., M.A., F.R.S.
Luby, Rev. Thomas.
Lyell, Charles, jun., M.A., F.R.S.
MacCullagh, Professor, D.C.L., M.R.I.A.
Macfarlane, The Very Rev. Principal.
MacLeay, William Sharp, F.L.S.
MacNeill, Professor Sir John, F.R.S.
Meynell, Thomas, Jun., F.L.S.
[illegible] Professor W. H., M.A., F.R.S.

Moilliet, J. L.
Moody, T. C., Esq.
Moody, T. F.
Morley, The Earl of.
Morpeth, Viscount, F.G.S.
Moseley, Rev. Henry, M.A., F.R.S.
Mount Edgecumbe, The Earl of.
Murchison, Sir Roderick I., G.C.S., F.R.S.
Neill, Patrick, M.D., F.R.S.E.
Nicol, Rev. J. P., LL.D.
Northampton, The Marquis of, President of the Royal Society.
Northumberland, The Duke of, K.G., M.A., F.R.S.
Norwich, The Bishop of, President of the Linnæan Society, F.R.S.
Ormerod, G. W., F.G.S.
Orpen, Thomas Herbert, M.D.
Owen, Professor Richard, M.D., F.R.S.
Oxford, The Bishop of, F.R.S., F.G.S.
Osler, Follett, F.R.S.
Palmerston, Viscount, G.C.B., M.P.
Peacock, Very Rev. George, D.D., Dean of Ely, V.P.R.S.
Pendarves, E., F.R.S.
Phillips, Professor John, F.R.S.
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Ritchie, Rev. Professor, LL.D., F.R.S.
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Robinson, Rev. T. R., D.D.
Robison, Sir John, Sec.R.S.Edin.
Roche, James.
Roget, Peter Mark, M.D., Sec.R.S.
Ross, Capt. Sir James C., R.N., F.R.S.
Rosse, The Earl of, F.R.S.
Royle, Professor John F., M.D., F.R.S.
Russell, James.
Sabine, Lieut.-Colonel Edward, R.A., For. Sec.R.S.
Sanders, William, F.G.S.
Sandon, Lord.
Scoresby, Rev. W., D.D., F.R.S.
Sedgwick, Rev. Professor, M.A., F.R.S.
Selby, Prideaux John, F.R.S.E.
Smith, Lt.-Colonel C. Hamilton, F.R.S.
Staunton, Sir George T., Bart., M.P., D.C.L., F.R.S.
Stevelly, Professor John, LL.D.
Strang, John.
Strickland, H. E., F.G.S.
Sykes, Lieut.-Colonel W. H., F.R.S.
Talbot, W. H. Fox, M.A., F.R.S.
Tayler, Rev. J. J.
Taylor, John, F.R.S.
Taylor, Richard, jun., F.G.S.
Thompson, William, F.L.S.
Traill, J. S., M.D.
Turner, Edward, M.D., F.R.S.
Turner, Samuel, F.R.S., F.G.S.
Turner, Rev. W.
Vigors, N. A., D.C.L., F.L.S.
Walker, James, F.R.S.
Walker, J. N., F.G.S.
Warburton, Henry, M.A., M.P., F.R.S.
Washington, Captain, R.N.
West, William, F.R.S.
Wheatstone, Professor, F.R.S.
Whewell, Rev. William, D.D., Master of Trinity College, Cambridge.
Williams, Professor Charles J. B., M.D., F.R.S.
Willis, Rev. Professor, M.A., F.R.S.
Winchester, The Marquis of.
Woollcombe, Henry, F.S.A.
Wortley, The Hon. John Stuart, B.A., M.P., F.R.S.
Yarrell, William, F.L.S.
Yarborough, The Earl of, D.C.L.
Yates, James, M.A., F.R.S.

THE GENERAL TREASURER'S ACCOUNT from 19th of June

RECEIPTS.

	£	s.	d.	£	s.	d.
To Life Compositions received at the Cambridge Meeting and since				185	0	0
To Annual Subscriptions.....Ditto.....Ditto.....Ditto.....				161	0	0
To Associates' Tickets .....Ditto.....Ditto.....Ditto.....				407	0	0
To Ladies' Tickets .....Ditto.....Ditto.....Ditto.....				172	0	0
To Book Compositions .....Ditto.....Ditto.....Ditto.....				64	0	0
To Dividends on Stock .....Ditto.....Ditto.....Ditto.....				225	14	6
To Sale of £1000 in the 3 per cent. Consols				956	5	0
To Cash from Cambridge Local Fund Committee				73	5	7
To Ditto portion of Grant returned				6	0	0
To received from the Sale of Publications:—						
of 1st volume	2	2	5			
of 2nd volume	2	12	0			
of 3rd volume	5	3	0			
of 4th volume	3	5	8			
of 5th volume	2	18	5			
of 6th volume	4	0	4			
of 7th volume	3	15	0			
of 8th volume	5	15	2			
of 9th volume	7	9	0			
of 10th volume	9	11	8			
of 11th volume	7	3	6			
of 12th volume	14	13	7			
of 13th volume	93	17	10			
of 14th volume	10	4	0			
of Lithograph Signatures	1	0	5			
				173	12	0
Balance carried on				125	3	1
				£2549	0	2

To Balance due to the General Treasurer				237	16	10
To Ditto due from Local Treasurers	7	19	6			
To Ditto in the Bankers' hands	104	14	3	112	13	9
				£125	3	1

The General Treasurer in Account

To Balance of Grant brought on from last Account	634	2	0
	£634	2	0

T. H. SHADWELL CLERKE,
D. T. ANSTED, } *Auditors.*

1845 (at Cambridge) to the 10th of September 1846 (at Southampton).

PAYMENTS.

	£	s.	d.	£	s.	d.
By Balance in advance on the General Account brought on...				360	10	5
By Sundry Disbursements by Treasurer and Local Treasurers, including the Expenses of the Meeting at Cambridge, Advertising, Sundry Printing, &c.....				203	11	5
By Printing, &c. of the 14th Report (13th vol.)				774	2	4
By Salaries to Assistant General Secretary, Accountant, &c. 18 months to Midsummer 1846.....				525	0	0
By Paid to the order of Committees on Account of Grants for Scientific purposes, viz. for—						
British Association Catalogue of Stars 1844	211	15	0			
Fossil Fishes of the London Clay	100	0	0			
Computation of the Gaussian Constants for 1839	50	0	0			
Maintaining the Establishment at Kew Observatory	146	16	7			
Experiments on the Strength of Materials	60	0	0			
Researches in Asphyxia.....	6	16	2			
Examination of Fossil Shells	10	0	0			
Vitality of Seeds 1844	2	15	10			
Ditto.....ditto.....1845	7	12	3			
Marine Zoology of Cornwall	10	0	0			
Ditto.....Ditto.....Britain	10	0	0			
Exotic Anoplura.....1844	25	0	0			
Expenses attending Anemometers.....	11	7	6			
Anemometers' Repairs	2	3	6			
Researches on Atmospheric Waves	3	3	3			
Captive Balloons.....1844	8	19	8			
Varieties of the Human Race.....1844	7	6	3			
Statistics of Sickness and Mortality at York	12	0	0			
				685	16	0
				£2549	0	2

By Balance in advance brought down as per contra £125 3 1

with the Government Grant.

By Amount Paid on Account of the Printing of Lalande and Lacaille's Catalogues.....	553	0	5
Balance in Treasurer's hands.....	81	1	7
	£634	2	0

OFFICERS AND COUNCIL, 1846–47.

Trustees (*permanent*).—Sir Roderick Impey Murchison, G.C.S^{t}.S., F.R.S. John Taylor, Esq., F.R.S. The Very Reverend George Peacock, D.D., Dean of Ely, F.R.S.

President.—Sir Roderick Impey Murchison, G.C.S^{t}.S., F.R.S.

Vice-Presidents.—The Marquis of Winchester. The Earl of Yarborough, D.C.L. Viscount Palmerston, G.C.B., M.P. Lord Ashburton, D.C.L. The Bishop of Oxford, F.R.S., F.G.S. The Right Hon. the Speaker, Charles Shaw Lefevre, M.P., F.G.S. Sir George T. Staunton, Bart., M.P., D.C.L., F.R.S. Professor Owen, M.D., F.R.S. Rev. Professor Powell, F.R.S.

President Elect.—Sir Robert Harry Inglis, Bart., D.C.L., F.R.S., M.P. for the University of Oxford.

Vice-Presidents Elect.—The Earl of Rosse, F.R.S. The Lord Bishop of Oxford, F.R.S. The Vice-Chancellor of the University of Oxford. Thomas G. Bucknall Estcourt, Esq., D.C.L., M.P. for the University of Oxford. The Very Rev. The Dean of Westminster, D.D., F.R.S., Professor of Geology and Mineralogy, Oxford. Charles G. B. Daubeny, M.D., F.R.S., Professor of Chemistry and Botany, Oxford. The Rev. Baden Powell, M.A., F.R.S., Savilian Professor of Geometry, Oxford.

General Secretary.—Lieut.-Col. Sabine, For. Sec. R.S., Woolwich.

Assistant General Secretary.—John Phillips, Esq., F.R.S., York.

General Treasurer.—John Taylor, Esq., F.R.S., 2 Duke Street, Adelphi, London.

Secretaries for the Oxford Meeting in 1847.—Rev. Robert Walker, M.A., F.R.S., Reader in Experimental Philosophy, Oxford. Henry Wentworth Acland, Esq., B.M., F.R.S., Lee's Reader in Anatomy, Oxford.

Treasurer to the Oxford Meeting in 1847.—Rev. Edward Hill, M.A., F.G.S., Christ Church, Oxford.

Council.—Professor Ansted. Sir H. T. De la Beche. Major Shadwell Clerke. Professor E. Forbes. Dr. Fitton. Professor T. Graham. W. R. Grove, Esq. W. J. Hamilton, Esq. Sir John F. W. Herschel, Bart. James Heywood, Esq. William Hopkins, Esq. Leonard Horner, Esq. Robert Hutton, Esq. Capt. Ibbotson. Dr. Latham. Sir Charles Lemon, Bart. The Marquis of Northampton. G. R. Porter, Esq. Sir John Richardson, M.D. Rev. Dr. Robinson. Dr. Roget. Captain Sir James Ross, R.N. Prof. J. Forbes Royle, M.D. H. E. Strickland, Esq. Lieut.-Col. Sykes. T. Tooke, Esq. William Thompson, Esq. Professor Wheatstone. C. J. B. Williams, M.D. Professor Willis.

Local Treasurers.—W. Gray, jun., Esq., York. Rev. E. Hill, Oxford. C. C. Babington, Esq., Cambridge. J. H. Orpen, LL.D., Dublin. Charles Forbes, Esq., Edinburgh. Professor Ramsay, Glasgow. William Sanders, Esq., Bristol. Samuel Turner, Esq., Liverpool. G. W. Ormerod, Esq., Manchester. James Russell, Esq., Birmingham. William Hutton, Esq., Newcastle-on-Tyne. ——————————, Plymouth. James Roche, Esq., Cork. J. Sadleir Moody, Esq., Southampton.

Auditors.—Professor Ansted. Professor Willis. Major Shadwell Clerke.

OFFICERS OF SECTIONAL COMMITTEES AT THE SOUTHAMPTON MEETING.

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President.—Sir John F. W. Herschel, Bart., F.R.S., &c.

Vice-Presidents.—Sir D. Brewster, F.R.S. L. & E. Professor Wheatstone, F.R.S. Col. Colby, R.E., F.R.S. & M.R.I.A. The Master of Trinity College, Cambridge.

Secretaries.—Dr. Stevelly. G. G. Stokes, Esq. John Drew, Esq.

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President.—Michael Faraday, D.C.L., F.R.S.

Vice-Presidents.—Professor W. R. Grove, F.R.S. Dr. Andrews, F.R.S. Professor Johnston, F.R.S. Dr. Daubeny, F.R.S.

Secretaries.—Dr. Miller, F.R.S. Robert Hunt, Esq. Wm. Randall, Esq.

SECTION C.—GEOLOGY AND PHYSICAL GEOGRAPHY.

President.—Leonard Horner, F.R.S., Pres. of Geological Society.

Vice-Presidents.—The Very Rev. Dr. Buckland, Dean of Westminster. Sir Henry De la Beche, F.R.S., Director-General of the Geological Survey of the United Kingdom. William Henry Fitton, M.D., F.R.S. William Hopkins, F.R.S. (*For Geography*) G. B. Greenough, F.R.S.

Secretaries.—Robert A. Austen, F.G.S. Professor Oldham, M.R.I.A., F.G.S. J. H. Norton, M.D. (*For Geography*) Charles T. Beke, Ph.D.

SECTION D.—ZOOLOGY AND BOTANY.

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Vice-Presidents.—Charles Darwin, M.A., F.R.S. Dr. Robert Brown, F.R.S., V.P.L.S. Professor E. Forbes, F.R.S. H. E. Strickland, M.A., F.G.S.

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President.—Professor Owen, F.R.S.

Vice-Presidents.—Sir James Clark, F.R.S. Dr. Roget. Dr. J. Forbes. Dr. Fowler.

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SECTION G.—MECHANICS.

President.—Rev. Professor Willis, F.R.S.

Vice-Presidents.—Rev. Dr. Robinson, F.R.S. George Rennie, F.R.S. J. Scott Russell, F.R.S. W. Snow Harris, F.R.S.

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President.—Dr. Prichard.

Vice-Presidents.—Admiral Sir Charles Malcolm, P.Eth.Soc. Dr. R. G. Latham. Dr. Hodgkin.

Secretary.—Dr. King.

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Professor Agassiz, Neufchatel. M. Arago, Paris. Dr. A. D. Bache, Philadelphia. Professor Berzelius, Stockholm. Professor H. von Boguslawski, Breslau. Monsieur Boutigny d'Evreux, Paris. Professor Braschmann, Moscow. M. De la Rive, Geneva. Professor Dove, Berlin. Professor Dumas, Paris. Professor Ehrenberg, Berlin. Dr. Eisenlohr, Carlsruhe. Professor Encke, Berlin. Dr. A. Erman, Berlin. Professor Forchhammer, Copenhagen. Professor Henry, Princeton, United States. Professor Kreil, Prague. M. Kupffer, St. Petersburg. Dr. Langberg, Christiania. Baron de Selys Longchamps, Liège. M. Frisiani, Milan. Baron Alexander von Humboldt, Berlin. M. Jacobi, St. Petersburg. Professor Jacobi, Königsberg. Dr. Lamont, Munich. Baron von Liebig, Giessen. Professor Link, Berlin. Professor Matteucci, Pisa. Professor Middendorff, St. Petersburg. Dr. Œrsted, Copenhagen. Chevalier Plana, Turin. M. Quetelet, Brussels. Professor C. Ritter, Berlin. Professor H. Rose, Berlin. Professor Schumacher, Altona. Baron Senftenberg, Bohemia. Dr. Svanberg, Stockholm. Baron Sartorius von Waltershausen, Gotha. Professor Wartmann, Lausanne.

REPORT OF THE PROCEEDINGS OF THE COUNCIL IN 1845–46, PRESENTED TO THE GENERAL COMMITTEE AT SOUTHAMPTON, WEDNESDAY, SEPT. 9, 1846.

Report of the Council to the General Committee.

1. The Council have the very satisfactory duty to perform, of reporting to the General Committee that the resolutions of the Magnetical and Meteorological Conference, adopted by the General Committee at Cambridge, on the 25th of June 1845, were submitted to the Right Hon. Sir Robert Peel, Bart., by the President Sir John Herschel, Bart., accompanied by a communication from the Marquis of Northampton, President of the Royal Society, conveying the concurrence of that body in the recommendations contained therein; that they received a very favourable consideration from Her Majesty's Government, and that the recommendations connected with the British observatories, both at home and in the Colonies, are in progress of being carried out. The resolutions relating to the East Indian observatories and surveys have met with an equally favourable reception from the Hon. Court of Directors of the East India Company, and the recommendations which they contained have been approved and sanctioned. In accordance with the resolutions passed at Cambridge, therefore, the magnetic observatory at Greenwich is permanently continued upon the most extensive and efficient scale. The magnetical and meteorological observations are constituted a permanent branch of the duties of the astronomical observatories at the Cape of Good Hope, Bombay and Madras, and arrangements are in progress for making them also a permanent branch of the observations to be made at the Observatory at Paramatta. The detachment of the Royal Artillery, by whom the duties at the Cape of Good Hope have been hitherto performed, has been relieved by a permanent increase in the civil strength of the Astronomical Observatory at that station, and in like manner the officers of the Royal Navy who now form the establishment of the observatory at Van Diemen Island will be relieved as soon as the civil establishment at Paramatta is completed. The Ordnance Observatories at Toronto and St. Helena are continued until the close of 1848.

With reference to the recommendations relating to magnetic surveys,

magnetic survey of the Indian Seas by Lieut. Elliot, of the Madras Engineers, has received the sanction of the Hon. Court of Directors of the East India Company, and is now in progress. Also in the present summer, Lieut. Moore, of the Royal Navy, proceeded under the direction of the Lords of the Admiralty to Hudson's Bay, in one of the vessels belonging to the Hudson's Bay Company, for the purpose of connecting the observations of the Canadian Survey with those which the Expedition under Sir John Franklin is making in the seas to the north of the American Continent.

In accordance with the recommendation concerning the co-operation of foreign magnetical and meteorological observatories, communications were made, on the application of the President, by the Earl of Aberdeen, Her Majesty's principal Secretary of State for Foreign Affairs, to the governments of Russia, Austria, Prussia, Belgium, Sweden and Spain, from all of whom very favourable replies have been received.

2. The resolution passed by the General Committee, to the effect "that it is highly desirable to encourage, by specific pecuniary reward, the improvement of self-recording magnetical and meteorological apparatus, and that the Presidents of the Royal Society and of the British Association be requested to solicit the favourable consideration of Her Majesty's Government to this subject," has been brought under the notice of Government, and arrangements have been made to carry the recommendation into effect. Whilst on this subject the Council has also much pleasure in noticing that the President and Council of the Royal Society have granted £50 from the Wollaston Donation Fund to assist in the construction of apparatus devised by Mr. Ronalds for the self-registry of magnetical and meteorological instruments; which apparatus is in progress of completion at the Observatory of the British Association at Kew. The Council are persuaded that the General Committee will view with satisfaction this co-operation of the Royal Society and British Association for objects common to both, and for which the Observatory at Kew furnishes a very convenient locality.

3. The General Committee at Cambridge having passed a resolution, "That it be referred to the Council to take into consideration, before the next Meeting of the Association, the expediency of discontinuing the Kew Observatory,"—the Council appointed a Committee, consisting of the President (Sir John Herschel), the Dean of Ely, the Astronomer Royal, Professors Graham and Wheatstone, and Lieut.-Colonel Sabine, to collect information on the scientific purposes which the Kew Observatory has served, and on its general usefulness to science and to the Association; from whom they received the following report:—

"Kew Observatory, May 7, 1846. *Present*,—Sir J. F. W. Herschel, Bart., the Astronomer Royal, Professors Graham and Wheatstone, and Lieut.-Colonel Sabine.

"After an attentive examination of the present state of the establishment, and of other matters connected therewith, the following resolutions were unanimously adopted, viz.—

"That it be recommended to the General Committee that the establishment at Kew, the occupancy of which has been granted by Her Majesty to the British Association, be maintained in its present state of efficiency:—

"1. Because it affords, at a very inconsiderable expense, a local habitation to the Association, and a convenient depository for its books, manuscripts and apparatus.

"2. Because it has afforded to Members of the Association the means

of prosecuting many physical inquiries which otherwise would not have been entered upon.

"3. Because the establishment has already become a point of interest to scientific foreigners, several of whom have visited it.

"4. Because the grant of the occupancy of the building by Her Majesty, at the earnest request of the British Association, is an instance of Her Majesty's interest in, and approval of, the objects of the Association.

"5. Because, if the Association at the present time relinquish the establishment, it will probably never again be available for the purposes of science.

"6. Because it appears, both from the publications of the British Association and from the records in progress at the establishment, that a great amount of electrical and meteorological observation has been and continues to be made, and that a systematic inquiry into the intricate subject of atmospheric electricity has been carried out by Mr. Ronalds, which has been productive of very material improvements in that subject, and has in effect furnished the model of the processes conducted at the Royal Observatory; and because these inquiries are still in progress under local circumstances extremely favourable.

"7. Because other inquiries into the working of self-registering apparatus, both meteorological and magnetical, are in actual progress at the establishment, and that there is a distinct prospect of the facilities it affords being speedily much more largely profited by.

"8. Because the access to the Observatory from London to Members of the Association will shortly be greatly improved by railroads, and because the local facilities and conveniences of the establishment have been very greatly enhanced by alterations in its relations to the Commissioners of Woods and Forests.

"J. F. W. Herschel, *Chairman.*"

In presenting this Report to the General Committee, the Council requests that it may be understood to convey also the opinion of the Council.

4. The Council has received a letter from the honorary Secretary of the Literary and Philosophical Institution at Cheltenham, expressing, on the part of the Members of that Institution, deep regret that "circumstances have arisen which render uncertain their being able to give the British Association that welcome and generous reception which it would be their desire to do, and which they last year felt that they would have done had the Association been so circumstanced as to have accepted the invitation for the summer of 1846."

5. The Council has been informed by a letter from W. H. Grove, Esq., F.R.S., that a deputation has been appointed by the Mayor and Corporation of Swansea, the principal inhabitants, magistracy and country gentlemen of the neighbourhood, and by the Members of the Royal Institution of South Wales, to attend the Meeting at Southampton, for the purpose of inviting the British Association to hold their annual Meeting at Swansea at as early a period as may suit their convenience.

Southampton, September 9, 1846.

Recommendations adopted by the General Committee at the Southampton Meeting in September 1846.

Involving Applications to Government and Public Institutions.

That Her Majesty's Government be requested to direct the publication of the Meteorological Observations made by the Officers of the Irish Trigonometrical Survey at Mountjoy and the Pigeon House since the year 1834.

That application be made to Her Majesty's Government, to direct that during the progress of the Ordnance Trigonometrical Surveys in the North of Scotland, the so-called parallel roads of Glen Roy and the adjoining country be accurately surveyed, with the view of determining whether they are truly parallel and horizontal, the intervening distances, and their elevations above the present Sea-level.

Recommendations for Reports and Researches not involving Grants of Money.

That Mr. Hopkins be requested to furnish, at the next Meeting of the Association, a Report on the Theory of such movements and displacements of the Earth's Crust, as may be connected with Earthquakes.

That Mr. Mallet be requested to furnish, at the same time, a Report of the Static and Dynamic Facts which have been observed to be the results of Earthquakes, or connected with them.

That Mr. Ellis be requested to continue his Report on the recent Progress of Analysis.

That Professor Edward Forbes be requested to prepare a Report on the State of our knowledge of the Acalephæ.

That Mr. J. Scott Russell be requested to prepare a Report on the present condition of the Science of Naval Construction, including Steam Navigation.

That Mr. Robert Mallet be requested to continue his inquiry into the Corrosion of Iron Rails in and out of use.

That Mr. Robert Hunt be requested to continue his investigations with the Actinograph, and that Mr. Ronalds be associated with him (the instrument to be placed at Kew).

That Mr. Robert Hunt be requested to continue his investigations on the Influence of Light on the Growth of Plants.

That a Committee, consisting of The Master of Trinity College, Cambridge, and Capt. Sir James C. Ross, R.N., be requested to draw up a Plan for a Naval Expedition for the purpose of completing our knowledge of the progress of the Tides.

That the Master of Trinity College, Cambridge be requested to draw up brief Instructions for Tide-observations by Voyagers and Surveyors, with a view to a speedy determination of the course of the Tide-wave.

That Professor Forchhammer's paper on Sea-Currents be printed entire among the Reports of the Association.

That Professor Owen's paper on the Homologies of the Cranial Vertebræ be printed entire among the Reports of the Association.

Recommendations of Special Researches in Science, involving Grants of Money.

KEW OBSERVATORY.

That the sum of £150 be placed at the disposal of the Council for the purpose of maintaining the establishment in Kew Observatory.

MATHEMATICAL AND PHYSICAL SCIENCE.

That £50 be placed at the disposal of Professor Erman for continuing and completing the computation of the Gaussian Constants for 1839, and that he be requested to superintend the same.

That Mr. Birt be requested to endeavour to procure a repetition of the Barometric Observations made during the month of November in former years; and that the sum of £10 be placed at his disposal for the purpose.

That a provisional grant of £70 be placed at the disposal of the Committee for the publication of the Catalogues of Lalande and Lacaille, to enable them to complete the publication and distribution of those Catalogues.

That a grant of £10 be made for a new Anemometer of the Rev. Dr. Robinson's improved construction, for the use of the Observatory at Kew; and that Dr. Robinson be requested to superintend its construction.

CHEMICAL SCIENCE.

That Dr. Percy and Professor Miller be requested to continue the examination of Crystalline Slags, and the quantity of impurities which perfect Crystals may contain; and that £20 be placed at their disposal for the purpose.

That Dr. Schunck be requested to continue his investigations on Colouring Matters, and that the sum of £10 be placed at his disposal for the purpose.

ZOOLOGY AND BOTANY.

That Mr. H. E. Strickland, Dr. Daubeny, Professor Lindley and Professor Henslow, be requested to continue their experiments on the Vitality of Seeds, and that the sum of £10 be placed at their disposal for the purpose.

That Capt. Portlock, R.E., be requested to continue his investigations into the Marine Zoology of Corfu by means of the dredge, and that the sum of £10 be placed at his disposal for the purpose.

That a Committee, consisting of Sir Charles Lemon and Mr. Couch, be requested to aid Mr. Peach in his Researches into the Marine Zoology of Cornwall, and that the sum of £10 be placed at their disposal for the purpose.

That a Committee, consisting of Prof. E. Forbes, Mr. Goodsir, Mr. Patterson, Mr. Thompson, Mr. Ball, Mr. J. Smith, Mr. Couch, Dr. Allman, Mr. M'Andrew, Mr. Alder, and the Rev. F. W. Hope, be requested to continue their investigations into the Marine Zoology of Britain by means of the dredge, and that the sum of £10 be placed at their disposal for the purpose.

That Sir Philip Egerton, Professor Owen, and Professor E. Forbes, be a Committee for aiding Mr. Price in his Researches into the Habits of Marine Animals, and that the sum of £10 be placed at their disposal for the purpose.

That Mr. Newport be requested to draw up a Report on the Scorpionidæ and Tracheary Arachnidæ, and that the sum of £10 be placed at the disposal of Mr. Spence and Mr. Wollaston for the purpose.

That Professor Owen and Mr. R. Taylor be a Committee to superintend the publication of Tabular Form[illegible] to the Report of periodical phæ-

nomena of Animals and Vegetables, and that £10 be placed at their disposal for the purpose.

MEDICAL SCIENCE.

That a Committee, consisting of Dr. J. Blake and Professor Sharpey, be requested to continue their Researches into the Action of Medicines, and that the sum of £20 be placed at their disposal for the purpose.

That the second and third parts of Dr. Carpenter's Report on the Microscopic structure of Shells, be illustrated by lithographic plates, not exceeding twenty.

Synopsis of Grants of Money appropriated to Scientific Objects by the General Committee at the Southampton Meeting, September 1845, *with the Name of the Member, who alone or as the First of a Committee, is entitled to draw for the Money.*

	£	s.	d.
Kew Observatory.			
For maintaining the establishment in Kew Observatory under the direction of the Council	150	0	0
Mathematical and Physical Science.			
Erman, A.—For Computation of the Gaussian Constants for 1839	50	0	0
Birt, W.—Researches on Atmospheric Waves	10	0	0
Robinson, Rev. Dr.—Construction of a New Anemometer	10	0	0
(Committee).—Completion of Catalogue of Stars	70	0	0
Chemical Science.			
Percy, Dr.—On Crystalline Slags, &c.	20	0	0
Schunck, Dr.—On Colouring Matters	10	0	0
Zoology and Botany.			
Strickland, H. E.—Vitality of Seeds	10	0	0
Portlock, Capt.—Marine Zoology of Corfu	10	0	0
Lemon, Sir Charles, Bart.—Marine Zoology of Cornwall	10	0	0
Forbes, Prof. E.—Marine Zoology of Britain	10	0	0
Egerton, Sir Philip, Bart.—Habits of Marine Animals	10	0	0
Spence, William.—On Scorpionidæ and Arachnidæ	10	0	0
Owen, Prof.—Tabular Forms for Registering Periodical Phænomena	10	0	0
Physiology.			
Blake, Dr.—Physiological Action of Medicines	20	0	0
Total of Grants	£410	0	0

Dr. Carpenter's Report on the Microscopic Structure of Shells, &c., to be illustrated by Plates, not exceeding Twenty in number.

General Statement of Sums which have been paid on Account of Grants for Scientific Purposes.

	£	s.	d.
1834.			
Tide Discussions	20	0	0
1835.			
Tide Discussions	62	0	0
BritishFossil Ichthyology	105	0	0
	£167	0	0
1836.			
Tide Discussions	163	0	0
BritishFossil Ichthyology	105	0	0
Thermometric Observations, &c.....	50	0	0
Experiments on long-continued Heat	17	1	0
Rain Gauges	9	13	0
Refraction Experiments	15	0	0
Lunar Nutation	60	0	0
Thermometers	15	6	0
	£434	14	0
1837.			
Tide Discussions.....	284	1	0
Chemical Constants ..	24	13	6
Lunar Nutation	70	0	0
Observations on Waves.	100	12	0
Tides at Bristol	150	0	0
Meteorology and Subterranean Temperature .	89	5	0
VitrificationExperiments	150	0	0
Heart Experiments....	8	4	6
Barometric Observations	30	0	0
Barometers	11	18	6
	£918	14	6
1838.			
Tide Discussions.....	29	0	0
British Fossil Fishes ..	100	0	0
Meteorological Observations and Anemometer (construction)	100	0	0
Cast Iron (strength of) .	60	0	0
Animal and Vegetable Substances (preservation of)	19	1	10
Carried forward	£308	1	10

	£	s.	d.
Brought forward	308	1	10
Railway Constants	41	12	10
Bristol Tides	50	0	0
Growth of Plants	75	0	0
Mud in Rivers	3	6	6
Education Committee ..	50	0	0
Heart Experiments....	5	3	0
Land and Sea Level ..	267	8	7
Subterranean Temperature	8	6	0
Steam-vessels	100	0	0
Meteorological Committee	31	9	5
Thermometers	16	4	0
	£956	12	2
1839.			
Fossil Ichthyology	110	0	0
Meteorological Observations at Plymouth ..	63	10	0
Mechanism of Waves ..	144	2	0
Bristol Tides	35	18	6
Meteorology and Subterranean Temperature .	21	11	0
VitrificationExperiments	9	4	7
Cast Iron Experiments.	100	0	0
Railway Constants	28	7	2
Land and Sea Level ..	274	1	4
Steam-Vessels' Engines.	100	0	0
Stars in Histoire Céleste	331	18	6
Stars in Lacaille	11	0	0
Stars in R.A.S.Catalogue	6	16	6
Animal Secretions	10	10	0
Steam-engines in Cornwall	50	0	0
Atmospheric Air.....	16	1	0
Cast and Wrought Iron.	40	0	0
Heat on Organic Bodies	3	0	0
Gases on Solar Spectrum	22	0	0
Hourly Meteorological Observations, Inverness and Kingussie ..	49	7	0
Fossil Reptiles	118	2	0
Mining Statistics.....	50	0	0
	£1595	11	0

	£	s.	d.
1840.			
Bristol Tides	100	0	0
Subterranean Temperature	13	13	6
Heart Experiments....	18	19	0
Lungs Experiments ..	8	13	0
Tide Discussions.....	50	0	0
Land and Sea Level ..	6	11	1
Stars (Histoire Céleste)	242	10	0
Stars (Lacaille)	4	15	0
Stars (Catalogue)	264	0	0
Atmospheric Air.....	15	15	0
Water on Iron.....	10	0	0
Heat on Organic Bodies	7	0	0
Meteorological Observations	52	17	6
Foreign Scientific Memoirs	112	1	6
Working Population ..	100	0	0
School Statistics	50	0	0
Forms of Vessels	184	7	0
Chemical and Electrical Phænomena.....	40	0	0
Meteorological Observations at Plymouth ..	80	0	0
Magnetical Observations	185	13	9
	£1546	16	4

	£	s.	d.
1841.			
Observations on Waves.	30	0	0
Meteorology and Subterranean Temperature .	8	8	0
Actinometers	10	0	0
Earthquake Shocks ..	17	7	0
Acrid Poisons.....	6	0	0
Veins and Absorbents..	5	0	0
Mud in Rivers.....	5	0	0
Marine Zoology	15	12	8
Skeleton Maps	20	0	0
Mountain Barometers..	6	18	6
Stars (Histoire Céleste).	185	0	0
Stars (Lacaille)	79	5	0
Stars (Nomenclature of)	17	19	6
Stars (Catalogue of) ..	40	0	0
Water on Iron.....	50	0	0
Meteorological Observations at Inverness ..	20	0	0
Meteorological Observations (reduction of)..	25	0	0
Carried forward	£539	10	8

	£	s.	d.
Brought forward	539	10	8
Fossil Reptiles	50	0	0
Foreign Memoirs	62	0	0
Railway Sections	38	1	6
Forms of Vessels	193	12	0
Meteorological Observations at Plymouth ..	55	0	0
Magnetical Observations	61	18	8
Fishes of the Old Red Sandstone	100	0	0
Tides at Leith.....	50	0	0
Anemometer at Edinburgh	69	1	10
Tabulating Observations	9	6	8
Races of Men.....	5	0	0
Radiate Animals.....	2	0	0
	£1235	10	11

	£	s.	d.
1842.			
Dynamometric Instruments	113	11	2
Anoplura Britanniæ ..	52	12	0
Tides at Bristol	59	8	0
Gases on Light	30	14	7
Chronometers	26	17	6
Marine Zoology	1	5	0
British Fossil Mammalia	100	0	0
Statistics of Education..	20	0	0
Marine Steam-vessels' Engines	28	0	0
Stars (Histoire Céleste)	59	0	0
Stars (British Association Catalogue of) ..	110	0	0
Railway Sections.....	161	10	0
British Belemnites	50	0	0
Fossil Reptiles (publication of Report)	210	0	0
Forms of Vessels.....	180	0	0
Galvanic Experiments on Rocks	5	8	6
Meteorological Experiments at Plymouth..	68	0	0
Constant Indicator and Dynamometric Instruments	90	0	0
Force of Wind.....	10	0	0
Light on Growth of Seeds	8	0	0
Vital Statistics	50	0	0
Vegetative Power of Seeds	8	1	11
Carried forward	£1442	8	8

	£	s.	d.
Brought forward	1442	8	8
Questions on Human Race	7	9	0
	£1449	17	8

1843.

Revision of the Nomenclature of Stars	2	0	0
Reduction of Stars, British Association Catalogue	25	0	0
Anomalous Tides, Frith of Forth	120	0	0
Hourly Meteorological Observations at Kingussie and Inverness	77	12	8
Meteorological Observations at Plymouth	55	0	0
Whewell's Meteorological Anemometer at Plymouth	10	0	0
Meteorological Observations, Osler's Anemometer at Plymouth	20	0	0
Reduction of Meteorological Observations	30	0	0
Meteorological Instruments and Gratuities	39	6	0
Construction of Anemometer at Inverness	56	12	2
Magnetic Co-operation	10	8	10
Meteorological Recorder for Kew Observatory	50	0	0
Action of Gases on Light	18	16	1
Establishment at Kew Observatory, Wages, Repairs, Furniture, and Sundries	133	4	7
Experiments by Captive Balloons	81	8	0
Oxidation of the Rails of Railways	20	0	0
Publication of Report on Fossil Reptiles	40	0	0
Coloured Drawings of Railway Sections	147	18	3
Registration of Earthquake Shocks	30	0	0
Report on Zoological Nomenclature	10	0	0
Carried forward	£977	6	7

	£	s.	d.
Brought forward	977	6	7
Uncovering Lower Red Sandstone near Manchester	4	4	6
Vegetative Power of Seeds	5	3	8
Marine Testacea (Habits of)	10	0	0
Marine Zoology	10	0	0
Marine Zoology	2	14	11
Preparation of Report on British Fossil Mammalia	100	0	0
Physiological operations of Medicinal Agents	20	0	0
Vital Statistics	36	5	8
Additional Experiments on the Forms of Vessels	70	0	0
Additional Experiments on the Forms of Vessels	100	0	0
Reduction of Observations on the Forms of Vessels	100	0	0
Morin's Instrument and Constant Indicator	69	14	10
Experiments on the Strength of Materials	60	0	0
	£1565	10	2

1844.

Meteorological Observations at Kingussie and Inverness	12	0	0
Completing Observations at Plymouth	35	0	0
Magnetic and Meteorological Co-operation	25	8	4
Publication of the British Association Catalogue of Stars	35	0	0
Observations on Tides on the East Coast of Scotland	100	0	0
Revision of the Nomenclature of Stars..1842	2	9	6
Maintaining the Establishment in Kew Observatory	117	17	3
Instruments for Kew Observatory	56	7	3
Carried forward	£384	2	4

	£	s.	d.
Brought forward	384	2	4
Influence of light on Plants	10	0	0
Subterraneous Temperature in Ireland	5	0	0
Coloured Drawings of Railway Sections	15	17	6
Investigation of Fossil Fishes of the Lower Tertiary Strata	100	0	0
Registering the Shocks of Earthquakes, 1842	23	11	10
Researches into the Structure of Fossil Shells	20	0	0
Radiata and Mollusca of the Ægean and Red Seas.....1842	100	0	0
Geographical distributions of Marine Zoology 1842	0	10	0
Marine Zoology of Devon and Cornwall ..	10	0	0
Marine Zoology of Corfu	10	0	0
Experiments on the Vitality of Seeds.....	9	0	3
Experiments on the Vitality of Seeds..1842	8	7	3
Researches on Exotic Anoplura.....	15	0	0
Experiments on the Strength of Materials	100	0	0
Completing Experiments on the Forms of Ships	100	0	0
Inquiries into Asphyxia	10	0	0
Investigations on the internal Constitution of Metals.....	50	0	0
Constant Indicator and Morin's Instrument, 1842	10	3	6
	£981	12	8

1845.

Publication of the British Association Catalogue of Stars	351	14	6
Meteorological Observations at Inverness ..	30	18	11
Magnetic and Meteorological Co-operation	16	16	8
Carried forward	£399	10	1

	£	s.	d.
Brought forward	399	10	1
Meteorological Instruments at Edinburgh	18	11	9
Reduction of Anemometrical Observations at Plymouth.....	25	0	0
Electrical Experiments at Kew Observatory	43	17	8
Maintaining the Establishment in Kew Observatory	149	15	0
For Kreil's Barometrograph	25	0	0
Gases from Iron Furnaces	50	0	0
Experiments on the Actinograph.....	15	0	0
Microscopic Structure of Shells	20	0	0
Exotic Anoplura..1843	10	0	0
Vitality of Seeds..1843	2	0	7
Vitality of Seeds..1844	7	0	0
Marine Zoology of Cornwall	10	0	0
Physiological Action of Medicines	20	0	0
Statistics of Sickness and Mortality in York ..	20	0	0
Registration of Earthquake Shocks ..1843	15	14	8
	£831	9	9

1846.

British Association Catalogue of Stars, 1844	211	15	0
Fossil Fishes of the London Clay	100	0	0
Computation of the Gaussian Constants for 1839	50	0	0
Maintaining the Establishment at Kew Observatory	146	16	7
Experiments on the Strength of Materials	60	0	0
Researches in Asphyxia	6	16	2
Examination of Fossil Shells	10	0	0
Vitality of Seeds..1844	2	15	10
Vitality of Seeds..1845	7	12	3
Marine Zoology of Cornwall	10	0	0
Carried forward	£605	15	10

	£	s.	d.
Brought forward	605	15	10
Marine Zoology of Britain	10	0	0
Exotic Anoplura..1844	25	0	0
Expenses attending Anemometers.....	11	7	6
Anemometers' Repairs .	2	3	6
Carried forward	654	6	10

	£	s.	d.
Brought forward	654	6	10
Researches on Atmospheric Waves.....	3	3	3
Captive Balloons..1844	8	19	8
Varieties of the Human Race 1844	7	6	3
Statistics of Sickness and Mortality at York ..	12	0	0
	£685	16	0

Extracts from Resolutions of the General Committee.

Committees and individuals, to whom grants of money for scientific purposes have been entrusted, are required to present to each following meeting of the Association a Report of the progress which has been made ; with a statement of the sums which have been expended, and the balance which remains disposable on each grant.

Grants of pecuniary aid for scientific purposes from the funds of the Association expire at the ensuing meeting, unless it shall appear by a Report that the Recommendations have been acted on, or a continuation of them be ordered by the General Committee.

In each Committee, the Member first named is the person entitled to call on the Treasurer, John Taylor, Esq., 2 Duke Street, Adelphi, London, for such portion of the sum granted as may from time to time be required.

In grants of money to Committees, the Association does not contemplate the payment of personal expenses to the Members.

In all cases where additional grants of money are made for the continuation of Researches at the cost of the Association, the sum named shall be deemed to include, as a part of the amount, the specified balance which may remain unpaid on the former grant for the same object.

On Thursday evening, September 10th, at 8 P.M., in the Victoria Rooms, Southampton, the late President, Sir John F. W. Herschel, Bart., F.R.S., resigned his office to Sir Roderick Impey Murchison, G.C.S^{t}.S., F.R.S., who took the Chair at the General Meeting, and delivered an Address, for which see p. xxvii.

On Friday evening, September 11th, in the same room, Professor Owen, F.R.S., delivered a Discourse on the Fossil Mammalia of the British Islands.

On Monday evening, in the same room, Charles Lyell, Esq., F.R.S., delivered a Discourse on the Valley and Delta of the Mississippi, and other points in the Geology of the United States, from observations made in the years 1845–46.

On Tuesday evening, in the same room, W. R. Grove, Esq. explained the properties of the Explosive Substance recently discovered by Dr. Schönbein; and communicated some recent researches of his own, on the Decomposition of Water into its constituent Gases by Heat.

On Wednesday evening, at 8 P.M., in the same room, the Concluding General Meeting of the Association was held, when the Proceedings of the General Committee, and the grants of money for scientific purposes, were explained to the Members.

The Meeting was adjourned to Oxford, on the 24th of June, 1847.

ADDRESS

BY

SIR RODERICK IMPEY MURCHISON, G.C.St.S., F.R.S., V.P.G.S.

&c. &c.

UNIVERSITY OF CALIFORNIA

Gentlemen,—After fifteen years of migration to various important cities and towns in the United Kingdom, you are for the first time assembled in the South-Eastern districts of England, at the solicitation of the authorities and inhabitants of Southampton. Easily accessible on all sides to the cultivators of science, this beautiful and flourishing sea-port is situated in a tract so adorned by nature, and so full of objects for scientific contemplation, that, supported as we are by new friends in England, and by old friends from distant parts of Europe, we shall indeed be wanting to ourselves, if our proceedings on this occasion should not support the high character which the British Association has hitherto maintained.

For my own part, though deeply conscious of my inferiority to my eminent predecessor in the higher branches of science, I still venture to hope, that the devotion I have manifested to this Association from its origin to the present day, may be viewed by you as a guarantee for the zealous execution of my duties. Permit me then, Gentlemen, to offer you my warmest acknowledgements for having placed me in this enviable position; and to assure you, that I value the approbation which it implies as the highest honour which could have been bestowed on me—an honour the more esteemed from its being conferred in a county endeared to me by family connexions, and in which I rejoice to have made my first essay as a geologist.

The origin, progress and objects of this our "Parliament of Science" have been so thoroughly explained on former occasions by your successive Presidents, particularly in reference to that portion of our body which cultivates the mathematical, chemical and mechanical sciences, that after briefly alluding to some of the chief results of bygone years, with a view of impressing upon our new members the general advances we have made, I shall in this address dwell more particularly on the recent progress and present state of natural history, the department of knowledge with which my own pursuits have been most connected, whilst I shall also incidentally advert to some of the proceedings which are likely to occupy our attention during this Meeting.

No sooner, Gentlemen, had this Association fully established its character as a legitimate representative of the science of the United Kingdom, and by its published Reports, the researches which it instituted, and the other substantial services which it rendered to science, had secured public respect, than it proceeded towards the fulfilment of the last of the great objects which a Brewster and a Harcourt contemplated at its foundation, by inviting the attention of the Government to important national points of scientific interest. At the fourth Meeting held in Edinburgh, the Association memorialized the Government to increase the forces of the Ordnance Geographical Survey of Britain, and to extend speedily to Scotland the benefits which had been already applied by that admirable establishment to the South of England, Wales and Ireland. From that time to the present it has not scrupled to cal'

the notice of the Ministers of the day to every great scientific measure which seemed, after due consideration, likely to promote the interests or raise the character of the British nation. Guided in the choice of these applications by a committee selected from among its members, it has sedulously avoided the presentation of any request which did not rest on a rational basis, and our rulers, far from resisting such appeals, have uniformly and cordially acquiesced in them. Thus it was when, after paying large sums from our own funds for the reduction of masses of astronomical observations, we represented to the Government the necessity of enabling the Astronomer Royal to perform the same work on the observations of his predecessors which had accumulated in the archives of Greenwich, our appeal was answered by arrangements for completing so important a public object at the public expense. Thus it was, when contemplating the vast accession to pure science as well as to useful maritime knowledge, to be gained by the exploration of the South Polar regions, that we gave the first impulse to the project of the great Antarctic expedition, which, supported by the influence of the Royal Society and its noble President, obtained the full assent of the Government, and led to results which, through the merits of Sir James Ross and his companions, have shed a bright lustre on our country, by copious additions to geography and natural history, and by affording numerous data for the development of the laws that regulate the magnetism of the earth.

The mention of terrestrial magnetism brings with it a crowd of recollections honourable to the British Association, from the perspicuous manner in which every portion of fresh knowledge on this important subject has been stored up in our volumes, with a view to generalization, by Colonel Sabine and others; whilst a wide field for its diffusion and combination has been secured by the congress held at our last meeting, at which some of the most distinguished foreign and British magneticians were assembled under the presidency of Sir John Herschel.

It is indeed most satisfactory for us to know, that not only did all the recommendations of the Association on this subject which were presented to our Government meet with a most favourable reception, but that in consequence of the representations made by Her Majesty's Secretary of State for Foreign Affairs to the public authorities of other countries which had previously taken part in the system of cooperative observation, the Governments of Russia, Austria, Prussia and Belgium have notified their intention of continuing their respective magnetical and meteorological observations for another term of three years.

In passing by other instances in which public liberality has been directed to channels of knowledge which required opening out, I must not omit to notice the grant obtained from our gracious Sovereign, of the Royal Observatory at Kew, which, previously dismantled of its astronomical instruments, has, under the suggestions of Professor Wheatstone, been converted by us into a station for observations purely physical, and especially for those details of atmospheric phænomena which are so minute and numerous, and require such unremitting attention, that they imperiously call for separate establishments. In realizing this principle, we can now refer British and foreign philosophers to our own observatory at Kew, where I have the authority of most adequate judges for saying they will find that a great amount of electrical and meteorological observation has been made, and a systematic inquiry into the intricate subject of atmospheric electricity carried out by Mr. Ronalds, to which no higher praise can be given, than that it has, in fact, furnished the model of the processes conducted at the Royal

Observatory of Greenwich. This establishment is besides so useful through the facilities which it offers for researches into the working of self-registering instruments which are there constructed, that I earnestly hope it may be sustained as heretofore by annual grants from our funds, particularly as it is accomplishing considerable results at very small cost.

Our volume for the last year contains several communications on physical subjects from eminent foreign cultivators of science, whom we have the pleasure of reckoning amongst our corresponding members, and whose communications, according to the usage of the Association, have been printed entire amongst the reports. In a discussion of the peculiarities by which the great comet of 1843 was distinguished, Dr. Von Boguslawski of Breslau has taken the occasion to announce the probability, resting on calculations which will be published in Schumacher's 'Astronomische Nachrichten,' of the identity of this comet with several of a similar remarkable character recorded in history, commencing with the one described by Aristotle, which appeared in the year 371 before our æra: should his calculations be considered to establish this fact, Dr. Von Boguslawski proposes that the comet should hereafter be distinguished by the name of "Aristotle's Comet." This communication contains also some highly ingenious and important considerations relating to the physical causes of the phænomena of the tails of comets.

Dr. Paul Erman of Berlin, father of the adventurous geographical explorer and magnetician who was one of the active members of the magnetic congress at Cambridge, has communicated through his son some interesting experiments on the electro-dynamic effects of the friction of conducting substances, and has pointed out the differences between these and normal thermo-electric effects. Baron von Senftenberg (who is an admirable example of how much may be done by a liberal zeal for science combined with an independent fortune) has published an account of the success with which self-registering meteorological instruments have been established at his observatory at Senftenberg, as well as at the national observatory at Prague.

Of our own members, Mr. Birt has contributed a second report on Atmospheric Waves, in continuation of the investigation which originated in the discussion by Sir John Herschel, of the meteorological observations which, at his suggestion, were made in various parts of the globe, at the periods of the equinoxes and solstices, commencing with the year 1834.

In a communication to the Meeting of the Association at York, Colonel Sabine traced with great clearness (from the hourly observations at Toronto) the effect of the single diurnal and single annual progressions of temperature, in producing on the mixed vapourous and gaseous elements of the atmosphere, the well-known progressions of daily and yearly barometrical pressure. To the conclusions which he then presented, and which apply, perhaps generally, to situations not greatly elevated in the interior of large tracts of land, the same author has added, in the last volume, a valuable explanation of the more complicated phænomena which happen at points where land and sea breezes, flowing with regularity, modify periodically and locally the constitution and pressure of the atmosphere. Taking for his data the two-hourly observations executed at the observatory of Bombay by Dr. Buist, Colonel Sabine has succeeded in demonstrating for this locality *a double daily progression of gaseous pressure*, in accordance with the flow and re-flow of the air from surfaces of land and water which are unequally affected by heat. And thus the diurnal variation of the daily pressure at a point within the tropics, and on the margin of the sea, is explained by the same reasoning which was suggested by facts observed in the interior of the vast continent of North America.

Among the many useful national objects which have been promoted by the physical researches of the British Association, there is one which calls for marked notice at this time, in the proposal of Mr. Robert Stephenson to carry an iron tube or suspended tunnel over the Menai Straits to sustain the great railway to Holyhead. This bold proposal could never have been realized, if that great engineer had not been acquainted with the progress recently made in the knowledge of the strength of materials, and specially of iron; such knowledge being chiefly due to investigations in which the Association has taken and is still taking a conspicuous share, by the devotion of its friends and the employment of its influence—investigations which have, as you know, been prosecuted with great zeal and success by its valued members Mr. Hodgkinson and Mr. Fairbairn. I may further state, that in the recent improvements in railways the aid of scientific investigations having been called for by the civil engineer, to assist him in determining with accuracy the power to be provided for attaining the high velocities of fifty and sixty miles an hour; it was found and admitted by the most eminent engineers, that the very best data for this purpose, and indeed the only experiments of any practical value, were those which had been provided for some years ago by a Committee of the British Association, as published in our Transactions. Let such results as these be our answer when we are asked, what have been the useful objects attained by the British Association!

However imperfect my knowledge of experimental philosophy may be, I must now notice that the last volume of our Reports contains two contributions to it, in which subjects of the deepest theoretical and practical interest have been elucidated, at the request of the Association, by the labours of our foreign coadjutors.

That some substance of a peculiar kind everywhere exists, or is formed in the atmosphere by electrical agency, both natural and artificial, had long been suspected, especially from the persistency of the odour developed by such agency, and its transference by contact to other matter. Professor Schönbein, to whom I shall hereafter advert as the author of an important practical discovery, is, however, the first philosopher who undertook to investigate the nature of that substance; and though the investigation is not yet complete, he has been enabled to report no inconsiderable progress in this difficult and refined subject of research.

A request from the Association to Professor Bunsen of Marburg, and our countryman Dr. Lyon Playfair, coupled with a contribution of small amount towards the expenses involved in the undertaking, has produced a report on the conditions and products of iron-furnaces which is of considerable value in a commercial view to one of the most important of our manufactures, and possesses at the same time a very high interest to chemical science in some of the views which it developes. On the one hand it exhibits an entirely new theory of the reduction, by cyanogen gas as the chief agent, of iron from the ore; on the other it shows, that in addition to a vast saving of fuel, about 2 cwt. of sal-ammoniac may daily be collected at the single establishment of Alfreton, where the experiments were made; thus leading us to infer that in the iron-furnaces of Britain there may be obtained from vapour which now passes away, an enormous quantity of this valuable substance, which would materially lessen the dependence of our agriculturists on foreign *guano*. It is, indeed, most gratifying to observe, that in pursuing this inquiry into the gaseous contents of a blazing furnace of great height, our associates traced out, foot by foot, the most recondite chemical processes, and described the fiery products with the same accuracy as if their researches had been made on the table of a laboratory. Weighed however only in the scales of absolute

and immediate utility, the remarkable results of these skilful and elaborate experiments give them a character of national importance, and justly entitle the authors and the body which has aided them to the public thanks.

After this glance at the subjects of purely physical science treated of in the last volume of our Transactions, let us now consider the domains of natural history; and as one of the cultivators of a science which has derived its main support and most of its new and enlarged views from naturalists, let me express the obligation which geologists are under to this Association, for having aided so effectively in bringing forth the zoological researches of Owen, Agassiz, and Edward Forbes. These three distinguished men have themselves announced, that in default of our countenance and assistance, they would not have undertaken, and never could have completed, some of their most important inquiries. Agassiz, for example, had not otherwise the means of comparing the ichthyolites of the British Isles with those of the continent of Europe. Without this impulse, Owen would not have applied his profound knowledge of comparative anatomy to British fossil saurians; and Edward Forbes might never have been the explorer of the depths of the Ægean, nor have revealed many hitherto unknown laws of submarine life, if his wishes and suggestions had not met with the warm support of our body, and been supported by its strongest recommendations to the Naval authorities.

Such allusions to naturalists, whose works have afforded the firmest supports to geology, might lead me to dilate at length on the recent progress of this science; but as the subject has been copiously treated at successive anniversaries of the Geological Society of London, and has had its recent advances so clearly enunciated by the actual President of that body who now presides over our Geological Section *, I shall restrain my "esprit de corps" whilst I briefly advert to some of the prominent advances which geologists have made. When our associate Conybeare reported to us at our second meeting, on the actual state and ulterior prospects of what he well termed the "archæology of the globe," he dwelt with justice on the numerous researches in different countries which had clearly established the history of a descent as it were into the bowels of the earth—which led us, in a word, downwards through those newer deposits that connect high antiquity with our own period, into those strata which support our great British coal-fields. Beyond this however the perspective was dark and doubtful—

"Res altâ terrâ et caligine mersas."

Now, however, we have dispersed this gloom, and by researches first carried out to a distinct classification in the British Isles, and thence extended to Russia and America, geologists have shown that the records of succession, as indicated by the entombment of fossil animals, are as unequivocally developed in these very ancient or palæozoic strata as in any of the overlying or more recently formed deposits. After toiling many years in this department of the science, in conjunction with Sedgwick, Lonsdale, De Verneuil, Keyserling, and others of my fellow-labourers, I have arrived at the conclusion, that we have reached the very genesis of animal life upon the globe, and that no separate and clearly definable "vestigia retrorsum" will be found beneath that protozoic or Lower Silurian group, in the great inferior mass of which scarcely a vertebrated animal has yet been detected, amid the profusion of the lower orders of marine animals entombed in it.

But however this may be, it is certain that in the last few years all Central

* Mr. Leonard Horner.

and Eastern Europe, including Turkey*, and even parts of Siberia have been brought into accordance with typical strata. France has been accurately classified and illustrated by the splendid map of Elie de Beaumont and Dufrenoy; and whilst, by the labours of Deshayes and others, its tertiary fossils have been copiously described, the organic remains of its secondary strata are now undergoing a complete analysis in the beautiful work of M. Alcide d'Orbigny. Belgium, whose mineral structure and geological outlines have been delineated by D'Omalius d'Halloy and Dumont, has produced very perfect monographs of its palæozoic and tertiary fossils; the first in the work of M. de Koningk, the second in the recently published monograph of M. Nyst. Germany, led on by Von Buch, has shown that she can now as materially strengthen the zoological and botanical groundworks of the science, as in the days of Werner she was eminent in laying those mineralogical foundations which have been brought so near to perfection by the labours of several living men. So numerous in fact have been the recent German contributions, that I cannot permit myself to specify the names of individuals in a country which boasts so many excellent geologists. As distinctly connected, however, with the objects of this Meeting, I must be permitted to state that the ingenious botanist Göppert, whose works, in combination with those of Adolphe Brongniart in France, have shed so much light on fossil plants, has just sent to me, for communication to our Geological Section, the results of his latest inquiries into the formation of the coal of Silesia—results which will be the more interesting to Dr. Buckland and the geologists of England, who have most attended to this subject, because they are founded on data equally new and original. Italy has also, to a great extent, been presented to us in its general geological facies, through the labours of Sismonda, Marmora, Pareto, Pasini, Catullo and others; whilst our kinsmen of the far West, with the true enterprise of the Saxon race, have so laid open the structure of their wide-spreading States, that our countryman Lyell has informed us, that the instructive map which accompanies his work upon North America is simply the grouping together of data prepared by native State geologists, which he has paralleled with our well-known British types.

If then the astronomer has, to a vast extent, expounded the mechanism of the heavens; if lately, through his large, new telescope, our associate the Earl of Rosse has assigned a fixity and order to bodies which were previously viewed as mere nebulæ floating in space, and has also inferred that the surface-cavities in our nearest neighbour of the planetary system are analogous to the volcanic apertures and depressions of the earth; the geologist, contributing data of another order to the storehouse of natural knowledge, has determined, by tangible proofs, the very manner in which our planet has been successively enveloped in divers cerements, each teeming with peculiar forms of distinct life, and has marked the revolutions which have interfered with these successive creations, from the earliest dawn of living things to the limits of the historic æra. In short, the fundamental steps gained in geology since the early days of the British Association, are so remarkable and so numerous, that the time has now come for a second report upon the progress of this science, which may I trust be prepared for an approaching Meeting.

Intimately connected with these broad views of the progress of geology is the appearance of the first volume of a national work by Sir Henry De la Beche and his associates in the Geological Survey of Great Britain. Following, as it does, upon the issue of numerous detailed coloured maps and

* See the geological map of Turkey by Boué, and that of Russia and the Ural Mountains by my coadjutors and myself.

sections, which for beauty of execution and exactness of detail are unrivalled, I would specially direct your attention to this new volume, as affording the clearest evidence that geology is now strictly brought within the pale of the fixed sciences. In it are found graphic descriptions of the strata in the South-West of England and South Wales, whose breadth and length are accurately measured, whose mineral changes are chemically analysed, and whose imbedded remains are compared and determined by competent palæontologists. The very statistics of the science are thus laid open, theory is made rigorously to depend on facts, and the processes and produce of foreign mines are compared with those of Britain.

When we know how intimately the Director-General of this Survey and his associates have been connected with the meetings of the British Association, and how they have freely discussed with us many parts of their researches—when we recollect that the geologist of Yorkshire, our invaluable Assistant General Secretary, around whom all our arrangements since our origin have turned, and to whom so much of our success is due, occupies his fitting place among these worthies—that Edward Forbes, who passed as it were from this Association to the Ægean, is the palæontologist of this Survey; and again when we reflect, that if this Association had not repaired to Glasgow, and there discovered the merits of the delineation of the Isle of Arran by Mr. Ramsay, that young geologist would never have become a valuable contributor to the volume under consideration—it is obvious from these statements alone, that the annual visits of our body to different parts of the Empire, by bringing together kindred spirits, and by testing the natural capacity of individuals, do most effectually advance science and benefit the British community.

Whilst considering these labours of the Government geologists, I shall now specially speak of those of Professor E. Forbes, because he here makes himself doubly welcome, by bringing to us as it were upon the spot the living specimens of submarine creatures, which through the praiseworthy enthusiasm of Mr. M^{c}Andrew, one of our members, who fitted out a yacht for natural-history researches, have been dredged up this summer by these naturalists from the southern coast, between the Land's End and Southampton. As a favourite yachting port like Southampton may, it is hoped, afford imitators, I point out with pleasure the liberal example of Mr. M^{c}Andrew, who although not professing to describe the specimens he collects, has now, as on former occasions, placed them in the hands of the members best qualified to do them justice, and is thus a substantial promoter of science.

The memoir, then, of Edward Forbes in the Government Geological Survey to which I now allude, is, in truth, an extension of his views respecting the causes of the present distribution of plants and animals in the British Isles, made known at the last meeting of the British Association. As this author has not only shown the application of these ideas to the researches of the British Geological Survey, but also to the distribution of animals and plants over the whole earth, it is evident that these views, in great part original, will introduce a new class of inquiries into natural history, which will link it on more closely than ever to geology and geography. In short, this paper may be viewed as the first attempt to explain the *causes* of the zoological and botanical features of any region anciently in connexion. Among the new points which it contains, I will now only mention, that it very ingeniously (and I trust satisfactorily) explains the origin of the peculiar features of the botany of Britain—the theory of the origin of Alpine Floras distributed far apart—the peculiarity of the zoology of Ireland as compared with that of England—the presence of the same species of marine

animals on the coasts of America and Europe—the specialities of the marine zoology of the British seas called for by this Association—the past and present distribution of the great Mediterranean Flora;—and lastly, it applies the knowledge we possess of the distribution of plants to the elucidation of the history of the superficial detritus, termed by geologists the "Northern Drift."

Amid the numerous subjects for reflection which the perusal of this memoir occasions, I must now restrict myself to two brief comments. First, to express my belief that even Humboldt himself, who has written so much and so admirably on Alpine floras, will admit that our associate's explanation of the origin of identity removes a great stumbling-block from the path of botanical geographers. Secondly, having myself for some years endeavoured to show, that the Alpine glacialists had erroneously applied their views, as founded on terrestrial phænomena, to large regions of Northern Europe, which must have been under the sea during the distribution of erratic blocks, gravel and boulders, I cannot but consider it a strong confirmation of that opinion, when I find so sound a naturalist as Edward Forbes sustaining the same view by perfectly independent inferences concerning the migration of plants to isolated centres, and by a studious examination and comparison of all the sea shells associated with these transported materials. And if I mistake not, my friend Mr. Lyell will find in both the above points, strong evidences in support of his ingenious climatal theories.

Recent as the blocks and boulders to which I have alluded may seem to be, they were however accumulated under a glacial sea, whose bottom was first raised to produce that connexion between the continent and Britain, by which the land animals migrated from their parent East to our western climes; a connexion that was afterwards broken through by the separation of our islands, and by the isolation in each of them of those terrestrial races which had been propagated to it. This latter inference was also, indeed, thoroughly sustained by the researches of Professor Owen, communicated to this Association; first, in the generalization by which his report on the Extinct Mammals of Australia is terminated, and still more in detailed reference to our islands in his recently published work 'On the Extinct Fossil British Mammalia,'—a work which he has stated in his dedication originated at the call of the British Association. Professor Owen, who fills a Vice-President's chair, adds, indeed, greatly to the strength of our present Meeting, by also acting as the President of one of our Sections, which having in its origin been exclusively occupied in the study of Medicine, is now more peculiarly devoted to the cultivation of Physiology. Under such a leader I have a right to anticipate, that this remodelled Section will exhibit evidences of fresh vigour, and will clearly define the vast progress that has been made in general and comparative anatomy since the days of Hunter and of Cuvier, for so large a part of which we are indebted to our eminent associate. I may, indeed, confidently announce, from what I know of the communications about to be made to us by Professor Owen on anatomical homologies, that our Members will be highly gratified in seeing our next volume enhanced with subjects from his pen, which hitherto have almost exclusively occupied the attention of continental anatomists.

Assembled in a county which has the good fortune to have been illustrated by the attractive history of the naturalist of Selborne, I am confident that our Fourth Section, to whose labours I would next advert, will yield a rich harvest, the more so as it is headed by that great zoologist who has enriched the adjacent Museum of the Naval Hospital at Haslar with so many animals from various parts of the world, and has so arranged them as to render

them objects well-worthy of your notice. The report of Sir John Richardson in the last volume, on the Fishes of China, Japan and New Zealand, when coupled with his account in former volumes of the Fauna of North America, may be regarded as having completely remodelled our knowledge of the geographical distribution of fishes; first by affording the data, and next by explaining the causes through which a community of ichthyological characters is in some regions widely spread, and in others restricted to limited areas. We now know, that just as the lofty mountain is the barrier which separates different animals and plants, as well as peculiar varieties of man, so the deepest seas are limits which peremptorily check the wide diffusion of certain genera and species of fishes; whilst the interspersion of numerous islands, and still more the continuance of lands throughout an ocean, ensures the distribution of similar forms over many degrees of latitude and longitude.

The general study, indeed, both of zoology and botany has been singularly advanced by the labours of the Section of Natural History. I cannot have acted for many years as your General Secretary without observing, that by the spirit in which this Section has of late years been conducted, British naturalists have annually become more philosophical, and have given to their inquiries a more physiological character, and have more and more studied the higher questions of structure, laws and distribution. This cheering result has mainly arisen from the personal intimacy brought about among various individuals, who, living at great distances from each other, were previously never congregated; and from the mutual encouragement imparted by their interchange of views and their comparisons of specimens. Many active British naturalists have in fact risen up since these Meetings commenced, and many (in addition to the examples already mentioned) have pursued their science directly under the encouragement we have given them. The combination of the enthusiastic and philosophic spirit thus engendered among the naturalists, has given popularity to their department of science, and this Section, assuming an importance to which during our earliest Meetings it could show comparatively slender claims, has vigorously revived the study of natural history, and among other proofs of it, has given rise to that useful publishing body the Ray Society, which holds its anniversary during our sittings. Any analysis of the numerous original and valuable reports and memoirs on botanical and zoological subjects which have occupied our volumes is forbidden by the limits of this address, but I cannot omit to advert to the extensive success of Mr. H. Strickland's report on Zoological Nomenclature, which has been adopted and circulated by the naturalists of France, Germany, Sweden and America, and also by those of Italy headed by the Prince of Canino. In each of these countries the code drawn up by the Association has been warmly welcomed, and through it we may look forward to the signal advantage being gained, of the adoption of an uniform zoological nomenclature all over the globe.

Whilst investigations into the geographical distribution of animals and plants have occupied a large share of the attention of our Browns and our Darwins, it is pleasing to see that some members, chiefly connected with physical researches, are now bringing these data of natural history to bear upon climatology and physical geography. A committee of our naturalists, to whom the subject was referred, has published in our last volume a good series of instructions for the observation of the periodical phænomena of animals and plants, prepared by our foreign associate M. Quetelet, the Astronomer Royal of Belgium. Naturalists have long been collecting observations on the effects produced by the annual return of the seasons, but their various natural-history calendars being local, required comparison and

concentration, as originally suggested by Linnæus. This has now for the first time been executed by the Belgian Astronomer, who following out a plan suggested by himself at our Plymouth Meeting, has brought together the contributions and suggestions of the naturalists of his own country. When M. Quetelet remarks, "that the phases of the smallest insect are bound up with the phases of the plant that nourishes it; that plant itself being in its gradual development the product, in some sort, of all anterior modifications of the soil and atmosphere," he compels the admission, that the study which should embrace all periodical phænomena, both diurnal and annual, would of itself form a science as extended as instructive.

Referring you to M. Quetelet's report for an explanation of the dependence of the vegetable and animal kingdoms on the meteorology and physics of the globe, and hoping that the simultaneous observations he inculcates will be followed up in Britain, I am happy to announce, that the outline of a memoir on physical geography was some months ago put into my hands by Mr. Cooley, which in a great degree coinciding with the system of M. Quetelet, has ultimately a different object. M. Quetelet chiefly aims at investigating the dependence of organized bodies on inorganized matter, by observing the periodical phænomena of the former. Mr. Cooley seeks to obtain an acquaintance with the same phænomena for the sake of learning and registering comparative climate as an element of scientific agriculture. Speaking to you in a county which is so mainly dependent on the produce of the soil, I cannot have a more favourable opportunity for inculcating the value of the suggestions of this British geographer. The complete establishment of all the data of physical geography throughout the British Islands; *i. e.* the registration of the mean and extremes of the temperature of the air and of the earth; the amount of conduction, radiation, moisture and magnetism; the succession of various phases of vegetation, &c. (with their several local corrections for elevation and aspect), must certainly advance the cause of science, and promote the material interests of our country.

A minute knowledge of all the circumstances of climate cannot but be of importance to those whose industry only succeeds through the co-operation of nature, and it may therefore be inferred, how a report like that with which I trust Mr. Cooley will favour us, if completed by the addition of tables, must prove to be a useful public document. Imbibing the ardour of that author, I might almost hope that such researches in physical geography may enable us to define, in the language of the poet,

"Et quid quæque ferat regio, et quid quæque recuset."

At all events, they will tend to raise physical geography in Britain towards the level it has attained in Prussia under the ægis of Humboldt and Ritter, and through the beautiful maps of Berghaus.

Though our countryman, Mr. Keith Johnston, is reproducing, in attractive forms, the comparative maps of the last-mentioned Prussian author, much indeed still remains to be done in Britain, to encourage the study of physical geography and to place it on a basis worthy of this great exploring and colonizing nation; and as one of the elementary aids to the training of the youthful mind to acquire some perception of the science, I commend the spirited project of M. Guerin of Paris, to establish in London a georama of vast size, the objects and details of which he intends to explain during this week to the geographers present.

Reverting to œconomical views and the improvement of lands, I would remind our agricultural members, that as their great practical Society was founded on the model of the British Association, we hope they will always

come to our Sections for the solution of any questions relating to their pursuits to which can be given a purely scientific answer. If they ask for the explanation of the dependence of vegetation upon subsoil or soil, our geologists and botanists are ready to reply to them. Is it a query on the comparison of the relative value of instruments destined to œconomize labour, the mechanicians now present are capable of answering it. And if, above all, they wish us to solve their doubts respecting the qualities of soils and the results of their mixtures, or the effects of various manures upon them, our chemists are at hand. One department of our Institution is, in fact, styled the Section of Chemistry and Mineralogy, with their applications to Agriculture and the Arts, and is officered in part by the very men, Johnston, Daubeny and Playfair, to whom the agriculturists have, in nearly all cases, appealed. The first-mentioned of these was one of our earliest friends and founders; the second had the merit of standing by the British Association at its first meeting, and there inviting us to repair to that great University where he is so much respected, and where he is now steadily determining, by elaborate experiments, the dependence of many species of plants on soil, air and stimulus; whilst the third has already been alluded to as one of our best actual contributors.

If in reviewing our previous labours I have endeavoured to gain your attention by some incidental allusions to our present proceedings, I have yet to assure you, that the memoirs communicated to our Secretaries are sufficiently numerous to occupy our Sections during the ensuing week with all the vigour which has marked our opening day. Among the topics to which our assembling at Southampton gives peculiar interest, I may still say that if geologists should find much to interest them in the Isle of Wight, the same island contains a field for a very curious joint discussion between them and the mathematicians, with which I became acquainted in a previous visit to this place. It is a discovery by Colonel Colby, the Director of the Trigonometrical Survey, of the existence of a notable attraction of the plumb-line to the south, at the trigonometrical station called Dunnose, on Shanklin Down. The details of this singular phænomenon, which has been verified by observations with the best zenith sectors, will be laid before the Sections. In the meantime, we may well wonder, that on the summit of a chalk hill of low altitude which is bounded on the south by the sea (near whose level the deviation is scarcely perceptible), there should exist an attraction of more than half the intensity of that which was registered by Maskelyne, when he suspended a plummet at the side of the lofty Scottish mountain of Schehallion! If those of our geologists, who like Mr. Hopkins of Cambridge have entered boldly into the field of geological dynamics, cannot explain this remarkable fact, by connecting it with the ridge of dislocated strata that runs through the island as a back-bone from west to east, may we venture to refer it to dense plutonic masses of rock ranging beneath the surface, parallel to the line of displacement of the deposits?

Another local subject—one indeed of positive practical interest—that stands before us for discussion, is, whether, by persevering in deepening the large shaft which they have sunk so deep into the chalk near this town, the inhabitants of Southampton may expect to be eventually repaid, like those of Paris, by a full supply of subterranean water, which shall rise to the surface of the low plateau on which the work has been undertaken? On no occasion, I must observe, could this town be furnished with a greater number of willing counsellors, whose opinions will, it is hoped, be adequately valued by the local authorities. The question whether this work ought to be proceeded with or not, will however, I apprehend, be most

effectively answered by those geologists who are best acquainted with the sections in the interior of this county, and with the levels at which the upper greensand and subcretaceous strata there crop out and receive the waters, which thence flow southwards beneath the whole body of chalk of the hills in the south of Hampshire.

Again, as we are now assembled in the neighbourhood of our great naval arsenal—as some of its functionaries, including the Admiral on the station, have honoured us with their support, and as, further, I am now speaking in a town whose magnificent new docks may compete with any for bold and successful engineering, I must say a few words on our naval architecture, the more so as we have here a Mechanical Section, presided over by the eminent mechanician Professor Willis, assisted by the great dynamical mathematician Dr. Robinson, and that sound engineer George Rennie. Duly impressed with the vast national importance of this subject, and at the same time of its necessary dependence on mathematical principles, the British Association endeavoured in its earliest days to rouse attention to the state of ship-building in England, and to the history of its progress in France and other countries, through a memoir by the late Mr. G. Harvey. It was then contended, that notwithstanding the extreme perfection to which the internal mechanism of vessels had been brought, their external forms or lines, on which their sailing so much depends, were deficient as to adjustment by mathematical theory. Our associate Mr. Scott Russell has, as you know, ably developed this view. Experimenting upon the resistance of water, and ascertaining with precision the forms of vessels which would pass through it with the least resistance, and consequently with the greatest velocity, he has contributed a most valuable series of memoirs, accompanied by a great number of diagrams, to illustrate his opinions and to show the dependence of naval architecture on certain mathematical lines. Employed, in the meantime, by merchants on their own account, to plan the construction of sailing ships and steamers, Mr. Scott Russell has been so successful in combining theory with practice, that we must feel satisfied in having at different meetings helped him onwards by several money grants; our only regret being, that our means should not have permitted us to publish the whole number of diagrams of the lines prepared by this ingenious author.

But however desirous to promote theoretical knowledge on this point, the men of science are far from wishing not to pay every deference to the skilful artificers of our wooden bulwarks, on account of their experience and practical acquaintance with subjects they have so long and so successfully handled. We are, indeed, fully aware, that the naval architects of the Government, who construct vessels carrying a great weight of metal and requiring much solidity and capacious stowage, have to solve many problems with which the owners of trading vessels or packets have little concern. All that we can wish for is, that our naval arsenals should contain schools or public boards of ship-building, in which there might be collected all the "constants of the art," in reference to capacity, displacement, stowage, velocity, pitching and rolling, masting, the effect of sails and the resistance of fluids. Having ourselves expended contributions to an extent which testify, at all events, our zeal in this matter, we are, I think, entitled to express a hope, that the data derived from practice by our eminent navigators may be effectively combined with the indications of sound theory prepared by approved cultivators of mathematical and mechanical science.

I cannot thus touch upon such useful subjects without saying, that our Statistical Section has been so well conducted by its former presidents, that its subjects, liable at all times to be diverted into moral considerations and thence

into politics, have been invariably restricted to the branch of the science which deals in facts and numbers; and as no one individual has contributed more to the storehouse of such valuable knowledge than Mr. George Porter (as evidenced even by his report in our last volume), so may we believe that in this town, with which he is intimately connected, he will contribute to raise still higher the claims of the Section over which he is so well qualified to preside.

If in this discourse I have referred somewhat more largely to those branches of science which pertain to the general division of natural history, in which alone I can venture to judge of the progress made by others, let me however say, that no member of this body can appreciate more highly than I do, the claims of the mathematical and experimental parts of philosophy, in which my friend Professor Baden Powell of Oxford, who supports me as a Vice-President of this meeting, has taken so distinguished a part. No one has witnessed with greater satisfaction the attendance at our former meetings of men, from all parts of Europe, the most eminent in these high pursuits. No one can more glory in having been an officer of this Association when it was honoured with the presence of its illustrious correspondent Bessel, than whom the world has never produced a more profound astronomer. If among his numerous splendid discoveries he furnished astronomers with what they had so long and so ardently desired—a fixed and ascertained point in the immensity of space, beyond the limits of our own sidereal system, it is to Bessel, as I am assured by a contemporary worthy of him, that Englishmen owe a debt of gratitude for his elaborate discussion of the observations of their immortal Bradley, which, in his hands, became the base of modern astronomy.

Passing from this recollection, so proud yet so mournful to us all as friends and admirers of the deceased Prussian astronomer, can any one see with more delight than myself the brilliant concurrence at our present Meeting of naturalists, geologists, physiologists, ethnologists and statists, with mathematicians, astronomers, mechanicians, and experimental philosophers in physics and in chemistry? Surely then I may be allowed to signalize a particular ground of gratification among so many, in the presence at this Meeting of two individuals in our Experimental Sections, to one of whom, our eminent foreign associate Oersted, we owe the first great link between electric and magnetic phænomena, by showing the magnetic properties of the galvanic current; whilst the other, our own Faraday, among other new and great truths which have raised the character of English science throughout the world, obtained the converse proof by evoking electricity out of magnets. And if it be not given to the geologist whom you have honoured with this chair, to explain how such arcana have been revealed, still, as a worshiper in the outer portico of the temple of physical science, he may be permitted to picture to himself the delight which the Danish philosopher must have felt, when on returning to our shores, after an absence of a quarter of a century, he found that the grand train of discovery of which he is the progenitor, had just received its crowning accession in England from his former disciple, who, after a long and brilliant series of investigations peculiarly his own, has shown that magnetic or dia-magnetic forces are distributed throughout all nature.

And thus shall we continue to be a true British Association, with cosmopolite connexions, so long as we have among us eminent men to attract such foreign contemporaries to our shores. If then at the last assembly we experienced the good effects which flowed from a concentration of mathematicians and magneticians, drawn together from different European kingdoms—if then also the man* of solid learning, who then represented the

* Mr. Everett.

United States of America, and who is now worthily presiding over the Cambridge University of his native soil, spoke to us with chastened eloquence of the benefits our Institution was conferring on mankind; let us rejoice that this Meeting is honoured by the presence of foreign philosophers as distinguished as those of any former year.

Let us rejoice that we have now among us men of science from Denmark, Sweden, Russia, Prussia, Switzerland, Italy and France. The King of Denmark, himself personally distinguished for his acquaintance with several branches of natural history, and a warm patron of science, has honoured us by sending hither, not only the great discoverer Oersted, who evincing fresh vigour in his mature age brings with him new communications on physical science, but also my valued friend, the able geologist and chemist Forchhammer, who has produced the first geological map of Denmark, and who has presented to us a lucid memoir on the influence exercised by marine plants on the formation of ancient crystalline rocks, on the present sea and on agriculture.

As these two eminent men and their associates of the North received me as the General Secretary of the British Association with their wonted cordiality at the last Scandinavian Scientific Assembly, I trust we may convince them that the sentiment is reciprocal, and that Englishmen are akin to them in the virtues of friendship and hospitality which so distinguish the dwellers within the circle of Odin.

Still adverting to Scandinavia, we see here a deputy from the country of Linnæus in the person of Professor Svanberg, a successful young experimenter in physics, who represents his great master Berzelius—that profound chemist and leader of the science of the North of Europe, who established on a firm basis the laws of atomic weights and definite proportions, and who has personally assured me, that if our Meeting had not been fixed in the month of September, when the agriculturists of Sweden assemble at Stockholm, he would assuredly have repaired to us. And if the same cause has prevented Nilsson from coming hither, and has abstracted Retzius from us (who was till within these few days in England), I cannot mention these distinguished men, who earnestly desired to be present, without expressing the hope, that the memoirs they communicate to us may give such additional support to our British ethnologists, as will enable this new branch of science, which investigates the origin of races and languages, to take the prominent place in our assemblies to which it is justly entitled.

The Royal Academy of Berlin, whose deputies on former occasions have been an Ehrenberg, a Buch, and an Erman, has honoured us by sending hither M. Heinrich Rosé, whose work on chemical analysis is a text-book even for the most learned chemists in every country; and whilst his researches on the constitution of minerals, like those of his eminent brother Gustave on their form, have obtained for him so high a reputation, he now brings to us the description of a new metal which he has discovered in the Tantalite of Bavaria.

Switzerland has again given to us that great master in palæontology, Agassiz, who has put arms into the hands of British geologists with which they have conquered vast regions, and who now on his road to new fields in America, brings to us his report on the fossil fishes of the basin of London, which will, he assures me, exceed in size all that he has ever written on ichthyolites.

From the same country we have our warm friend Professor Schönbein, who, in addition to his report on Ozone, to which I have already referred, has now brought to us a discovery which promises to be of vast practical importance. The "gun-cotton" of Schönbein, the powers of which he will exhibit to his

colleagues, is an explosive substance, which is stated to exercise a stronger projectile force than gunpowder, to possess the great advantages over it of producing little or no smoke or noise, and of scarcely soiling fire-arms; whilst no amount of wet injures this new substance, which is as serviceable after being dried as in its first condition. The mere mention of these properties, to which our associate lays claim for his new material, is sufficient to suggest its extraordinary value in warlike affairs, as also in every sort of subterranean blasting, and may well lead me to say, that this discovery, which may almost rival the invention of the substance which it is destined to supplant, will signally mark this meeting at Southampton. But, as if British chemistry were not to be outdone, here also there will be promulgated, for the first time, the very remarkable discovery of our countryman Mr. Grove, of the decomposition of water by heat.

Professor Matteucci of Modena, who joined us at the York meeting, and then explained his various new and delicate investigations in electro-physiology, again favours us with a visit, as the representative of the Italian Philosophical Society of Modena and of the University of Pisa. This ingenious philosopher, who has measured the effect of galvanic currents in exciting through the nerves mechanical force in the muscles, doubtless brings with him such interesting contribution as will add great additional interest to the proceedings of the Physiological Section.

Among these sources of gratification, no one has afforded me sincerer pleasure than to welcome hither the undaunted Siberian explorer, Professor von Middendorff. Deeply impressed as I am with the estimation in which science is held by the illustrious ruler of the empire of Russia, I cannot but hope that the presence of this traveller, so signalized by his enterprising exploits, may meet with a friend in every Englishman who is acquainted with the arduous nature of his travels. To traverse Siberia from south to north and from west to east; to reach by land the extreme northern headland of Taimyr; to teach us, for the first time, that even to the latitude of 72° north, trees with stems extend themselves in that meridian; that crops of rye, more abundant than in his native Livonia, grow beyond Yakutsk, on the surface of that frozen subsoil, the intensity and measure of cold in which he has determined by thermometric experiments; to explain, through their language and physical form, the origin of tribes now far removed from their parent stock; to explore the far eastern regions of the Sea of Ohkotsk and of the Shantar Isles; to define the remotest north-eastern boundary between China and Russia; and finally to enrich St. Petersburgh with the natural productions, both fossil and recent, of all these wild and untrodden lands, are the exploits for which the Royal Geographical Society of London has, at its last meeting, conferred its Gold Victoria Medal on this most successful explorer. Professor von Middendorff now visits us to converse with our naturalists most able to assist him, and to inspect our museums, in which, by comparison, he can best determine the value of specific characters before he completes the description of his copious accumulations; and I trust that during his stay in England he will be treated with as much true hospitality as I have myself received at the hands of his kind countrymen.

It is impossible for me to make this allusion to the Russian empire, without assuring you that our allies in science on the Neva, who have previously sent to us a Jacobi and a Kupffer, are warmly desirous of continuing their good connexion with us. It was indeed a source of great pleasure to me to he recently had personal intercourse in this very town with that eminent scien navigator Admiral Lütke, in whose squadron His Imperial Highness Grand Duke Constantine was acquiring a knowledge of his maritime d

Besides the narrative of his former voyages, Lütke has since published an account of the periodical tides in the Great Northern Ocean and in the Glacial Sea, which I have reason to think is little known in this country. Having since established a *hypsalographe* in the White Sea, and being also occupied from time to time in observations in Behring's Straits, the Russians will soon be able to provide us with other important additions to our knowledge of this subject. Separated so widely as Admiral Lütke and Dr. Whewell are from each other, it is pleasing to see, that the very recommendation which the last-mentioned distinguished philosopher of the tides has recently suggested to me, as a subject to be encouraged by this Association, has been zealously advocated by the former. Let us hope then that this Meeting will not pass away without powerfully recommending to our own Government, as well as to that of His Imperial Majesty, the carrying out of systematic and simultaneous investigations of the tides in the Great Ocean, particularly in the Northern Pacific,—a subject (as Admiral Lütke well observes) which is not less worthy of special expeditions and of the attention of great scientific bodies, than the present inquiries into terrestrial magnetism; and one which, I may add, this Association will doubtless warmly espouse, since it has such strong grounds for being satisfied with the results which it has already contributed to obtain through its own grants, and by the researches of several of its associates.

Lastly, in alluding to our foreign attendants, let us hope that our nearest neighbours may respond to our call, and may prove by their affluence to Southampton, that in the realms of science there is that "entente cordiale" between their great nation and our own, of which, at a former meeting, we were assured by the profound Arago himself. No sooner was it made known that the Chair of Chemistry at this Meeting was to be filled by Michael Faraday, than a compeer worthy of him in the Academy of Sciences of Paris was announced in the person of M. Dumas *, by a letter from that philosopher to myself. To M. Dumas it is well known that we owe, not only the discovery of the law of substitution of types, which has so powerfully aided the progress of organic chemistry, but also the successful application of his science to the arts and useful purposes of life; his great work on that subject, 'La Chimie appliquée aux Arts,' being as familiar in every manufactory in England as it is upon the Continent.

Nor, if we turn from chemistry to geology, will such of us as work among the rocks be backward in welcoming any French geologists who may come to examine, in our own natural sections of the Isle of Wight, the peculiar development of their Paris basin, the identity of their chalk and our own, the fine sections of our greensand and of the Wealden formation of Mantell, and to determine with us *in situ* the strict relations of their Neocomian rocks with those peculiar strata which at Atherfield, in the Isle of Wight, have been so admirably illustrated by Dr. Fitton and other native geologists, and of which such beautiful and accurate diagrams have been prepared by Captain Ibbetson.

Will it not then be admitted, that the gathering together of such foreign philosophers, as those above mentioned, with our own men of science, must be productive of good results? Putting aside even the acknowledged fact, that numerous memoirs of value are published in one country which are unknown in another, where is the person, acquainted with the present accelerated march of science, who can doubt that the germs of discovery which are floating in the minds of distant contemporaries, must often be brought to maturity by the interchange of such thoughts? The collision of these

* The resolution of M. Dumas to visit the Meeting was arrested by a sudden illness, and his apology only reached the President towards the close of the Meeting.

thoughts may indeed be compared to the agency of the electric telegraph of our own Wheatstone, which concentrates knowledge from afar, and at once unites the extremities of kingdoms in a common circle of intelligence.

But although the distinguished foreigners to whom I have adverted, and others, including our welcome associate M. Wartmann, the Founder of the Vaudois Society, and M. Prevost of Geneva, on whose merits I would willingly dilate if time permitted it, are now collected around us; many, among whom I must name M. de Caumont, the President of the French Society for the Advancement of Science, have been prevented from honouring us with their presence, because the national meetings in their several countries also occur in the month of September. To remedy this inconvenience, I ventured, when addressing you six years ago at the Glasgow meeting, to express the hope, that each of the European societies might be led to abstain during one year from assembling in its own country, for the purpose of repairing by its own deputies to a general congress, to be held at Frankfort or other central city under the presidency of the universal Humboldt. Had the preparation of the 'Cosmos' and other avocations of that renowned individual permitted him to accept this proposition, which the British Association would doubtless have supported, many benefits to science must have resulted, and each national body, on re-assembling the following year in its native land, would, I am convinced, have more vigorously resumed its researches.

But whether it be considered desirable or not to suspend the national scientific meetings during one year, I call on my countrymen and their foreign friends now present, to sustain the proposal for centralizing in a future year the representatives of the various branches of science of different countries, when they may at once learn the progress made in each nation, and when, at all events, they can so appoint the periods of their respective assemblies, as to prevent those simultaneous meetings in France, Germany, Scandinavia, Italy, Switzerland and England, which are so much to be deprecated as interfering with a mutual intercourse.

Finally, my fellow-labourers in science, if by our united exertions we have done and are doing good public service, let me revert once more to the place in which we are assembled, and express on your part the gratification I know you experience in being on this occasion as well supported by the noblemen, clergymen, and landed proprietors around Southampton, as by its inhabitants themselves—an union which thus testifies that the British Association embraces all parties and all classes of men.

Seeing near me Her Majesty's Secretary of State for Foreign Affairs, the Speaker of the House of Commons, and several persons of high station and great influence, who willingly indicate by their presence the sense they entertain of the value of our conferences and researches, let us welcome these distinguished individuals, as living evidences of that good opinion of our countrymen, the possession of which will cheer us onward in our career. And above all, let us cherish the recollection of this Southampton Meeting, which will be rendered memorable in our annals by the presence of the illustrious Consort of our beloved Sovereign, who participating in our pursuits, in some of which His Royal Highness is so well-versed, thus demonstrates that our Association is truly national, and enjoys the most general and effectual support throughout British society, from the humblest cultivators of science to the highest personages in the realm.

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Report on Recent Researches in Hydrodynamics.

By G. G. STOKES, *M.A., Fellow of Pembroke College, Cambridge.*

AT the meeting of the British Association held at Cambridge last year, the Committee of the Mathematical Section expressed a wish that a Report on Hydrodynamics should be prepared, in continuation of the reports which Prof. Challis had already presented to the Association on that subject. Prof. Challis having declined the task of preparing this report, in consequence of the pressure of other engagements, the Committee of the Association did me the honour to entrust it to me. In accordance with the wishes of the Committee, the object of the present report will be to notice researches in this subject subsequent to the date of the reports of Prof. Challis. It will sometimes however be convenient, for the sake of giving a connected view of certain branches of the subject, to refer briefly to earlier investigations.

The fundamental hypothesis on which the science of hydrostatics is based may be considered to be, that the mutual action of two adjacent portions of a fluid at rest is normal to the surface which separates them. The equality of pressure in all directions is not an independent hypothesis, but a necessary consequence of the former. This may be easily proved by the method given in the *Exercices* of M. Cauchy*, a method which depends on the consideration of the forces acting on a tetrahedron of the fluid, the dimensions of which are in the end supposed to vanish. This proof applies equally to fluids at rest and fluids in motion; and thus the hypothesis above-mentioned may be considered as the fundamental hypothesis of the ordinary theory of hydrodynamics, as well as hydrostatics. This hypothesis is fully confirmed by experiment in the case of the equilibrium of fluids; but the comparison of theory and experiment is by no means so easy in the case of their motion, on account of the mathematical difficulty of treating the equations of motion. Still enough has been done to show that the ordinary equations will suffice for the explanation of a great variety of phænomena; while there are others the laws of which depend on a tangential force, which is neglected in the common theory, and in consequence of which the pressure is different in different directions about the same point. The linear motion of fluids in uniform pipes and canals is a simple instance. In the following report I shall first consider the common theory of hydrodynamics, and then notice some theories which take account of the inequality of pressure in different directions. It will be convenient to consider the subject under the following heads:—

I. General theorems connected with the ordinary equations of fluid motion.

II. Theory of waves, including tides.

* Tom. ii. p. 42.

III. The discharge of gases through small orifices.

IV. Theory of sound.

V. Simultaneous oscillations of fluids and solids.

VI. Formation of the equations of motion when the pressure is not supposed equal in all directions.

I. Although the common equations of hydrodynamics have been so long known, their complexity is so great that little has been done with them except in the case in which the expression usually denoted by

$$u\,dx+v\,dy+w\,dz \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A.)$$

is the exact differential of a function of the independent variables x, y, z*. It becomes then of the utmost importance to inquire in what cases this supposition may be made. Now Lagrange enunciated two theorems, by virtue of which, supposing them true, the supposition may be made in a great number of important cases, in fact, in nearly all those cases which it is most interesting to investigate. It must be premised that in these theorems the accelerating forces X, Y, Z are supposed to be such that $Xdx+Ydy+Zdz$ is an exact differential, supposing the time constant, and the density of the fluid is supposed to be either constant, or a function of the pressure. The theorems are—

First, that (A.) is approximately an exact differential when the motion is so small that squares and products of u, v, w and their differential coefficients may be neglected. By calling (A.) approximately an exact differential, it is meant that there exists an expression $u_1dx+v_1dy+w_1dz$, which is accurately an exact differential, and which is such that u_1, v_1, w_1 differ from u, v, w respectively by quantities of the second order only.

Secondly, that (A.) is accurately an exact differential at all times when it is so at one instant, and in particular when the motion begins from rest.

It has been pointed out by Poisson that the first of these theorems is not true†. In fact, the initial motion, being arbitrary, need not be such as to render (A.) an exact differential. Thus those cases coming under the first theorem in which the assertion is true are merged in those which come under the second, at least if we except the case of small motions kept up by disturbing causes, a case in which we have no occasion to consider initial motion at all. This case it is true is very important.

The validity of Lagrange's proof of the second theorem depends on the legitimacy of supposing u, v and w capable of expansion according to positive, integral powers of the time t, for a sufficiently small value of that variable. This proof lies open to objection; for there are functions of t the expansions of which contain fractional powers, and there are others which cannot be expanded according to ascending powers of t, integral or fractional, even though they may vanish when $t=0$. It has been shown by Mr. Power that Lagrange's proof is still applicable if u, v and w admit of expansion according to ascending powers of t of any kind‡. The second objection however still remains: nor does the proof which Poisson has substituted for Lagrange's in his 'Traité de Mécanique' appear at all more satisfactory. Besides, it does not appear from these proofs what becomes of the theorem if it is only for a certain portion of the fluid that (A.) is at one instant an exact differential.

M. Cauchy has however given a proof of the theorem§, which is totally different from either of the former, and perfectly satisfactory. M. Cauchy

* In nearly all the investigations of Mr. Airy it will be found that (A.) is an exact differential, although he does not start with assuming it to be so.

† Mémoires de l'Académie des Sciences, tom. x. p. 554.

‡ Transactions of the Cambridge Philosophical Society, vol. vii. p. 455.

§ Mémoires des Savans Etrangers, tom. i. p. 40.

first eliminates the pressure by differentiation from the three partial differential equations of motion. He then changes the independent variables in the three resulting equations from x, y, z, t to a, b, c, t, where a, b, c are the initial co-ordinates of the particle whose co-ordinates at the time t are x, y, z. The three transformed equations admit each of being once integrated with respect to t, and the arbitrary functions of a, b, c introduced by integration are determined by the initial motion, which is supposed to be given. The theorem in question is deduced without difficulty from the integrals thus obtained. It is easily proved that if the velocity is suddenly altered by means of impulsive forces applied at the surface of the fluid, the alteration is such as to leave (A.) an exact differential if it were such before impact. M. Cauchy's proof shows moreover that if (A.) be an exact differential for one portion of the fluid, although not for the whole, it will always remain so for that portion. It should be observed, that although M. Cauchy has proved the theorem for an incompressible fluid only, the same method of proof applies to the more general case in which the density is a function of the pressure.

In a paper read last year before the Cambridge Philosophical Society, I have given a new proof of the same theorem*. This proof is rather simpler than M. Cauchy's, inasmuch as it does not require any integration.

In a paper published in the Philosophical Magazine†, Prof. Challis has raised an objection to the application of the theorem to the case in which the motion of the fluid begins from rest. According to the views contained in this paper, we are not in general at liberty to suppose (A.) to be an exact differential when u, v and w vanish: this supposition can only be made when the limiting value of $t^{-\alpha}(u\,dx+v\,dy+w\,dz)$ is an exact differential, where α is so taken as that one at least of the terms in this expression does not vanish when t vanishes.

It is maintained by Prof. Challis that the received equations of hydrodynamics are not complete, as regards the analytical principles of the science, and he has given a new fundamental equation, in addition to those received, which he calls the *equation of continuity of the motion*‡. On this equation Prof. Challis rests a result at which he has arrived, and which all must allow to be most important, supposing it correct, namely that whenever (A.) is an exact differential the motion of the fluid is necessarily rectilinear, one peculiar case of circular motion being excepted. As I have the misfortune to differ from Professor Challis on the points mentioned in this and the preceding paragraph, for reasons which cannot be stated here, it may be well to apprise the reader that many of the results which will be mentioned further on as satisfactory lie open to Prof. Challis's objections.

By virtue of the equation of continuity of a homogeneous incompressible fluid, the expression $u\,dy-v\,dx$ will always be the exact differential of a function of x and y. In the Cambridge Philosophical Transactions§ there will be found some applications of this function, and of an analogous function for the case of motion which is symmetrical about an axis, and takes place in planes passing through the axis. The former of these functions had been previously employed by Mr. Earnshaw.

II. In the investigations which come under this head, it is to be understood that the motion is supposed to be very small, so that first powers only of small quantities are retained, unless the contrary is stated.

* Transactions of the Cambridge Philosophical Society, vol. viii. p. 307.

† Vol. xxiv. New Series, p. 94.

‡ Transactions of the Cambridge Philosophical Society, vol. viii. p. 31; and Philosophical Magazine, vol. xxvi. New Series, p. 425.

§ Vol. vii. p. 439.

The researches of MM. Poisson and Cauchy were directed to the investigation of the waves produced by disturbing causes acting arbitrarily on a small portion of the fluid, which is then left to itself. The mathematical treatment of such cases is extremely difficult; and after all, motions of this kind are not those which it is most interesting to investigate. Consequently it is the simpler cases of wave motion, and those which are more nearly connected with the phænomena which it is most desirable to explain, that have formed the principal subject of more recent investigations. It is true that there is one memoir by M. Ostrogradsky, read before the French Academy in 1826*, to which this character does not apply. In this memoir the author has determined the motion of the fluid contained in a cylindrical basin, supposing the fluid at first at rest, but its surface not horizontal. The interest of the memoir however depends almost exclusively on the mathematical processes employed; for the result is very complicated, and has not been discussed by the author. There is one circumstance mentioned by M. Plana† which increases the importance of the memoir in a mathematical point of view, which is that Poisson met with an apparent impossibility in endeavouring to solve the same problem. I do not know whether Poisson's attempt was ever published.

Theory of Long Waves.—When the length of the waves whose motion is considered is very great compared with the depth of the fluid, we may without sensible error neglect the difference between the horizontal motions of different particles in the same vertical line, or in other words suppose the particles once in a vertical line to remain in a vertical line: we may also neglect the vertical, compared with the horizontal effective force. These considerations extremely simplify the problem; and the theory of long waves is very important from its bearing on the theory of the tides. Lagrange's solution of the problem in the case of a fluid of uniform depth is well known. It is true that Lagrange fell into error in extending his solution to cases to which it does not apply; but there is no question as to the correctness of his result when properly restricted, that is when applied to the case of long waves only. There are however many questions of interest connected with this theory which have not been considered by Lagrange. For instance, what will be the velocity of propagation in a uniform canal whose section is not rectangular? How will the form of the wave be altered if the depth of the fluid, or the dimensions of the canal, gradually alter?

In a paper read before the Cambridge Philosophical Society in May 1837‡, the late Mr. Green has considered the motion of long waves in a rectangular canal whose depth and breadth alter very slowly, but in other respects quite arbitrarily. Mr. Green arrived at the following results:—If β be the breadth, and γ the depth of the canal, then the height of the wave $\propto \beta^{-\frac{1}{2}}\gamma^{-\frac{1}{4}}$, the horizontal velocity of the particles in a given phase of their motion $\propto \beta^{-\frac{1}{2}}\gamma^{-\frac{3}{4}}$, the length of the wave $\propto \gamma^{\frac{1}{2}}$, and the velocity of propagation $= \sqrt{g\gamma}$. With respect to the height of the wave, Mr. Russell was led by his experiments to the same law of its variation as regards the breadth of the canal, and with respect to the effect of the depth he observes that the height of the wave increases as the depth of the fluid decreases, but that the variation of the height of the wave is very slow compared with the variation of the depth of the canal.

In another paper read before the Cambridge Philosophical Society in

* Mémoires des Savans Etrangers, tom. iii. p. 23.

† Turin [illegible] 1835, p. 253.

‡ Tra[illegible]mbridge Philosophical Society, vol. vi. p. 457.

February 1839*, Mr. Green has given the theory of the motion of long waves in a triangular canal with one side vertical. Mr. Green found the velocity of propagation to be the same as that in a rectangular canal of half the depth.

In a memoir read before the Royal Society of Edinburgh in April 1839†, Prof. Kelland has considered the case of a uniform canal whose section is of any form. He finds that the velocity of propagation is given by the very simple formula $\sqrt{\frac{gA}{b}}$, where A is the area of a section of the canal, and b the breadth of the fluid at the surface. This formula agrees with the experiments of Mr. Russell, and includes as a particular case the formula of Mr. Green for a triangular canal.

Mr. Airy, the Astronomer Royal, in his excellent treatise on Tides and Waves, has considered the case of a variable canal with more generality than Mr. Green, inasmuch as he has supposed the section to be of any form‡. If A, b denote the same things as in the last paragraph, only that now they are supposed to vary slowly in passing along the canal, the coefficient of horizontal displacement $\propto A^{-\frac{3}{4}} b^{\frac{1}{4}}$, and that of the vertical displacement $\propto A^{-\frac{1}{4}} b^{-\frac{1}{4}}$, while the velocity of propagation at any point of the canal is that given by the formula of the preceding paragraph. Mr. Airy has proved the latter formula§ in a more simple manner than Prof. Kelland, and has pointed out the restrictions under which it is true. Other results of Mr. Airy's will be more conveniently considered in connection with the tides.

Theory of Oscillatory Waves.—When the surface of water is covered with an irregular series of waves of different sizes, the longer waves will be continually overtaking the shorter, and the motion will be very complicated, and will offer no regular laws. In order to obtain such laws we must take a simpler case: we may for instance propose to ourselves to investigate the motion of a series of waves which are propagated with a constant velocity, and without change of form, in a fluid of uniform depth, the motion being in two dimensions and periodical. A series of waves of this sort may be taken as the *type* of oscillatory waves in general, or at least of those for which the motion is in two dimensions: to whatever extent a series of waves propagated in fluid of a uniform depth deviates from this standard form, to the same extent they fail in the characters of uniform propagation and invariable form.

The theory of these waves has long been known. In fact each element of the integrals by which MM. Poisson and Cauchy expressed the disturbance of the fluid denotes what is called by Mr. Airy a *standing oscillation*, and a progressive oscillation of the kind under consideration will result from the superposition of two of these standing oscillations properly combined. Or, if we merely replace products of sines and cosines under the integral signs by sums and differences, each element of the new integrals will denote a progressive oscillation of the standard kind. The theory of these waves however well deserves a more detailed investigation. The most important formula connected with them is that which gives the relation between the velocity of propagation, the length of the waves, and the depth of the fluid. If c be the velocity of propagation, λ the length of the waves, measured from crest to crest, h the depth of the fluid, and $m = \frac{2\pi}{\lambda}$, then

$$c^2 = \frac{g}{m} \frac{\varepsilon^{mh} - \varepsilon^{-mh}}{\varepsilon^{mh} + \varepsilon^{-mh}} \quad \ldots\ldots\ldots \text{(B.)}$$

* Transactions of the Cambridge Philosophical Society, vol. vii. p. 87.

† Transactions of the Royal Society of Edinburgh, vol. xiv. pp. 524, 530.

‡ Encyclopædia Metropolitana, article 'Tides and Waves.' Art. 260 of the treatise.

§ Art. 218, &c.

If the surface of the fluid be cut by a vertical plane perpendicular to the ridges of the waves, the section of the surface will be the curve of sines. Each particle of the fluid moves round and round in an ellipse, whose major axis is horizontal. The particle is in its highest position when the crest of the wave is passing over it, and is then moving in the direction of propagation of the wave; it is in its lowest position when the hollow of the wave is passing over it, and is then moving in a direction contrary to the direction of propagation. At the bottom of the fluid the ellipse is reduced to a right line, along which the particle oscillates. When the length of waves is very small compared with the depth of the fluid, the motion at the bottom is insensible, and all the expressions will be sensibly the same as if the depth were infinite. On this supposition the expression for c reduces itself to $\sqrt{\frac{g\lambda}{2\pi}}$. The ellipses in which the particles move are replaced by circles, and the motion in each circle is uniform. The motion decreases with extreme rapidity as the point considered is further removed from the surface; in fact, the coefficients of the horizontal and vertical velocity contain as a factor the exponential ϵ^{-my}, where y is the depth of the particle considered below the surface. When the depth of the fluid is finite, the *law* of the horizontal and vertical displacements of the particles is the same as when the depth is infinite. When the length of the waves is very great compared with the depth of the fluid, the horizontal motion of different particles in the same vertical line is sensibly the same. The expression for c reduces itself to $\sqrt{gh}$, the same as would have been obtained directly from the theory of long waves. The whole theory is given very fully in the treatise of Mr. Airy*. The nature of the motion of the individual particles, as deduced from a rigorous theory, was taken notice of, I believe for the first time, by Mr. Green†, who has considered the case in which the depth is infinite.

The oscillatory waves just considered are those which are propagated uniformly in fluid of which the depth is everywhere the same. When this condition is not satisfied, as for instance when the waves are propagated in a canal whose section is not rectangular, it is desirable to know how the velocity of propagation and the form of the waves are modified by this circumstance. There is one such case in which a solution has been obtained. In a paper read before the Royal Society of Edinburgh in January 1841, Prof. Kelland has arrived at a solution of the problem in the case of a triangular canal whose sides are inclined at an angle of 45° to the vertical, or of a canal with one side vertical and one side inclined at an angle of 45°, in which the motion will of course be the same as in one half of the complete canal‡. The velocity of propagation is given by the formula (B.), which applies to a rectangular canal, or to waves propagated without lateral limitation, provided we take for h half the greatest depth in the triangular canal, and for λ, or $\frac{2\pi}{m}$, a quantity less than the length of the waves in the triangular canal in the ratio of 1 to $\sqrt{2}$. As to the form of the waves, a section of the surface made by a vertical plane parallel to the edges of the canal is the curve of sines; a section made by a vertical plane perpendicular to the former is the common catenary, with its vertex in the plane of the middle of the canal (supposed complete), and its concavity turned upwards or downwards according as the section is taken where the fluid is elevated or where it is depressed. Thus

* Tides and Waves, art. 160, &c.

† Transactions of the Cambridge Philosophical Society, vol. vii. p. 95.

‡ Transactions of the Royal Society of Edinburgh, vol. xv. p. 121.

the ridges of the waves do not bend forwards, but are situated in a vertical plane, and they rise higher towards the slanting sides of the canal than in the middle. I shall write down the value of φ, the integral of (A.), and then any one who is familiar with the subject can easily verify the preceding results. In the following expression x is measured along the bottom line of the canal, y is measured horizontally, and z vertically upwards:—

$$\varphi = A\left(\varepsilon^{\alpha y}+\varepsilon^{-\alpha y}\right)\left(\varepsilon^{\alpha z}+\varepsilon^{-\alpha z}\right)\sin\sqrt{2}\,\alpha\,(x-ct). \quad . \quad . \quad . \quad . \quad (C.)$$

I have mentioned these results under the head of oscillatory waves, because it is to that class only that the investigation strictly applies. The length of the waves is however perfectly arbitrary, and when it bears a large ratio to the depth of the fluid, it seems evident that the circumstances of the motion of any one wave cannot be materially affected by the waves which precede and follow it, especially as regards the form of the middle portion, or ridge, of the wave. Now the solitary waves of Mr. Russell are long compared with the depth of the fluid; thus in the case of a rectangular canal he states that the length of the wave is about six times the depth. Accordingly Mr. Russell finds that the form of the ridge agrees well with the results of Prof. Kelland.

It appears from Mr. Russell's experiments that there is a certain limit to the slope of the sides of a triangular canal, beyond which it is impossible to propagate a wave in the manner just considered. Prof. Kelland has arrived at the same result from theory, but his mathematical calculation does not appear to be quite satisfactory. Nevertheless there can be little doubt that such a limit does exist, and that if it be passed, the wave will be either continually breaking at the sides of the canal, or its ridge will become bow-shaped, in consequence of the portion of the wave in the middle of the canal being propagated more rapidly than the portions which lie towards the sides. When once a wave has become sufficiently curved it may be propagated without further change, as Mr. Airy has shown*. Thus the case of motion above considered is in nowise opposed to the circumstance that the tide wave assumes a curved form when it is propagated in a broad channel in which the water is deepest towards the centre.

It is worthy of remark, that if in equation (C.) we transfer the origin to either of the upper edges of the canal (supposed complete), and then suppose h to become infinite, having previously written $A\,\varepsilon^{-\alpha h}$ for A, the result will express a series of oscillatory waves propagated in deep water along the edge of a bank having a slope of 45°, the ridges of the waves being perpendicular to the edge of the fluid. It is remarkable that the disturbance of the fluid decreases with extreme rapidity as the perpendicular distance from the edge increases, and not merely as the distance from the surface increases. Thus the disturbance is sensible only in the immediate neighbourhood of the edge, that is at a distance from it, which is a small multiple of λ. The formula may be accommodated to the case of a bank having any inclination by merely altering the coefficients of y and z, without altering the sum of the squares of the coefficients. If i be the inclination of the bank to the vertical, it will be easily found that the velocity of propagation is equal to $\left(\frac{g\lambda}{2\pi}\cos i\right)^{\frac{1}{2}}$. When i vanishes these waves pass into those already mentioned as the standard case of oscillatory waves; and when i becomes negative, or the bank overhangs the fluid, a motion of this sort becomes impossible.

* Tides and Waves, art. 359.

I have had occasion to refer to what Mr. Airy calls a *standing oscillation* or *standing wave*. To prevent the possibility of confusion, it may be well to observe that Mr. Airy uses the term in a totally different sense from Mr. Russell. The standing wave of Mr. Airy is the oscillation which would result from the coexistence of two series of progressive waves, which are equal in every respect, but are propagated in opposite directions. With respect to the standing wave of Mr. Russell, it cannot be supposed that the elevations observed in mountain streams can well be made the subject of mathematical calculation. Nevertheless in so far as the motion can be calculated, by taking a simple case, the theory does not differ from that of waves of other classes. For if we only suppose a velocity equal and opposite to that of the stream impressed both on the fluid and on the stone at the bottom which produces the disturbance, we pass to the case of a forced wave produced in still water by a solid dragged through it. There is indeed one respect in which the theory of these standing waves offers a peculiarity, which is, that the velocity of a current is different at different depths. But the theory of such motions is one of great complexity and very little interest.

Theory of Solitary Waves.—It has been already remarked that the length of the solitary wave of Mr. Russell is considerable compared with the depth of the fluid. Consequently we might expect that the theory of long waves would explain the main phænomena of solitary waves. Accordingly it is found by experiment that the velocity of propagation of a solitary wave in a rectangular canal is that given by the formula of Lagrange, the height of the wave being very small, or that given by Prof. Kelland's formula when the canal is not rectangular. Moreover, the laws of the motion of a solitary wave, deduced by Mr. Green from the theory of long waves, agree with the observations of Mr. Russell. Thus Mr. Green found, supposing the canal rectangular, that the particles in a vertical plane perpendicular to the length of the canal remain in a vertical plane; that the particles begin to move when the wave reaches them, remain in motion while the wave is passing over them, and are finally deposited in new positions; that they move in the direction of propagation of the wave, or in the contrary direction, according as the wave consists of an elevation or a depression*. But when we attempt to introduce into our calculations the finite length of the wave, the problem becomes one of great difficulty. Attempts have indeed been made to solve it by the introduction of discontinuous functions. But whenever such functions are introduced, there are certain conditions of continuity to be satisfied at the common surface of two portions of fluid to which different analytical expressions apply; and should these conditions be violated, the solution will be as much in fault as it would be if the fluid were made to penetrate the bottom of the canal. No doubt, the theory is contained, to a first approximation, in the formulæ of MM. Poisson and Cauchy; but as it happens the obtaining of these formulæ is comparatively easy, their discussion forms the principal difficulty. When the height of the wave is not very small, so that it is necessary to proceed to a second approximation, the theory of long waves no longer gives a velocity of propagation agreeing with experiment. It follows, in fact, from the investigations of Mr. Airy, that the velocity of propagation of a long wave is, to a second approximation, $\sqrt{g(h+3k)}$, where h is the depth of the fluid when it is in equilibrium, and $h+k$ the height of the crest of the wave above the bottom of the canal†.

* Transactions of the Cambridge Philosophical Society, vol. vii. p. 87.

† Tides and Waves, art. 208. In applying this formula to a *solitary* wave, it is necessary to take for h the depth of the undisturbed portion of the fluid. In the treatise of Mr. Airy the formula is obtained for a particular law of disturbance, but the same formula would have

The theory of the two great solitary waves of Mr. Russell forms the subject of a paper read by Mr. Earnshaw before the Cambridge Philosophical Society in December last*. Mr. Russell found by experiment that the horizontal motion of the fluid particles was sensibly the same throughout the whole of a vertical plane perpendicular to the length of the canal. He attributed the observed degradation of the wave, and consequent diminution of the velocity of propagation, entirely to the imperfect fluidity of the fluid, and its adhesion to the sides and bottom of the canal. Mr. Earnshaw accordingly investigates the motion of the fluid on the hypotheses,—first, that the particles once in a vertical plane, perpendicular to the length of the canal, remain in a vertical plane; secondly, that the wave is propagated with a constant velocity and without change of form. It is important to observe that these hypotheses are used not as a *foundation for calculation*, but as a *means of selecting* a particular kind of motion for consideration. The equations of fluid motion admit of integration in this case in finite terms, without any approximation, and it turns out that the motion is possible, *so far as the wave itself is concerned*, and everything is determined in the result except two constants, which remain arbitrary. However, in order that the motion in question should actually take place, it is necessary that there should be an instantaneous generation or destruction of a finite velocity, and likewise an abrupt change of pressure, at the junction of the portion of fluid which constitutes the wave with the portions before and behind which are at rest, both which are evidently impossible. It follows of course that one at least of the two hypotheses must be in fault. Experiment showing that the first hypothesis is very nearly true, while the second (from whatever cause) is sensibly erroneous, the conclusion is that in all probability the degradation of the wave is not to be attributed wholly to friction, but that it is an essential characteristic of the motion. Nevertheless the formula for the velocity of propagation of the positive wave, at which Mr. Earnshaw has arrived, agrees very well with the experiments of Mr. Russell; the formula for the negative wave also agrees, but not closely. These two formulæ can be derived from each other only by introducing imaginary quantities.

It is the opinion of Mr. Russell that the solitary wave is a phænomenon *sui generis*, in nowise deriving its character from the circumstances of the generation of the wave. His experiments seem to render this conclusion probable. Should it be correct, the analytical character of the solitary wave remains to be discovered. A complete theory of this wave should give, not only its velocity of propagation, but also the law of its degradation, at least of that part of the degradation which is independent of friction, which is probably by far the greater part. With respect to the importance of this peculiar wave however, it must be remarked that the term *solitary wave*, as so defined, must not be extended to the tide wave, which is nothing more (as far as regards the laws of its propagation) than a very long wave, of which the form may be arbitrary. It is hardly necessary to remark that the mechanical theories of the solitary wave and of the aërial sound wave are altogether different.

Theory of River and Ocean Tides.—The treatise of Mr. Airy already referred to is so extensive, and so full of original matter, that it will be impossible within the limits of a report like the present to do more than endeavour to

been arrived at, by the same reasoning, had the law not been restricted. This formula is given as expressing the velocity of propagation of the phase of high water, which it is true is not quite the same as the velocity of propagation of the crest of the wave; but the two velocities are the same to the second order of approximation.

* Transactions of the Cambridge Philosophical Society, vol. viii. p. 326.

give an idea of the nature of the calculations and methods of explanation employed, and to mention some of the principal results.

On account of the great length of the tide wave, the horizontal motion of the water will be sensibly the same from top to bottom. This circumstance most materially simplifies the calculation. The partial differential equation for the motion of long waves, when the motion is very small, is in the simplest case the same as that which occurs in the theory of the rectilinear propagation of sound; and in Mr. Airy's investigations the arbitrary functions which occur in its integral are determined by the conditions to be satisfied at the ends of the canal in which the waves are propagated, in a manner similar to that in which the arbitrary functions are determined in the case of a tube in which sound is propagated. When the motion is not very small, the partial differential equation of wave motion may be integrated by successive approximations, the arbitrary functions being determined at each order of approximation as before.

To proceed to some of the results. The simplest conceivable case of a tidal river is that in which the river is regarded as a uniform, indefinite canal, without any current. The height of the water at the mouth of the canal will be expressed, as in the open sea, by a periodic function of the time, of the form $a \sin(nt+\alpha)$. The result of a first approximation of course is that the disturbance at the mouth of the canal will be propagated uniformly up it, with the velocity due to half the depth of the water. But on proceeding to a second approximation*, Mr. Airy finds that the form of the wave will alter as it proceeds up the river. Its front will become shorter and steeper, and its rear longer and more gently sloping. When the wave has advanced sufficiently far up the river, its surface will become horizontal at one point in the rear, and further on the wave will divide into two. At the mouth of the river the greatest velocities of the ebb and flow of the tide are equal, and occur at low and high water respectively; the time during which the water is rising is also equal to the time during which it is falling. But at a station up the river the velocity of the ebb-stream is greater than that of the flow-stream, and the rise of the water occupies less time than its fall. If the station considered is sufficiently distant from the mouth of the river, and the tide sufficiently large, the water after it has fallen some way will begin to rise again: there will in fact be a double rise and fall of the water at each tide. This explains the double tides observed in some tidal rivers. The velocity with which the phase of high water travels up the river is found to be $\sqrt{gk(1+3b)}$, k being the depth of the water when in equilibrium, and bk the greatest elevation of the water at the mouth of the river above its mean level. The same formula will apply to the case of low water if we change the sign of b. This result is very important, since it shows that the interval between the time of the moon's passage over the meridian of the river station and the time of high water will be affected by the height of the tide. Mr. Airy also investigates the effect of the current in a tidal river. He finds that the difference between the times of the water's rising and falling is increased by the current.

When the canal is stopped by a barrier the circumstances are altered. When the motion is supposed small, and the disturbing force of the sun and moon is neglected, it is found in this case that the tide-wave is a stationary wave†, so that there is high or low water at the same instant at every point of the canal; but if the length of the canal exceeds a certain quantity, it is high water in certain parts of the canal at the instant when it is low water

* Art. 198, &c. † Art. 307.

in the remainder, and *vice versâ*. The height of high water is different in different parts of the canal: it increases from the mouth of the canal to its extremity, provided the canal's length does not exceed a certain quantity. If four times the length of the canal be any odd multiple of the length of a free wave whose period is equal to that of the tide, the denominator of the expression for the tidal elevation vanishes. Of course friction would prevent the elevation from increasing beyond a certain amount, but still the tidal oscillation would in such cases be very large.

When the channel up which the tide is propagated decreases in breadth or depth, or in both, the height of the tide increases in ascending the channel. This accounts for the great height of the tides observed at the head of the Bristol Channel, and in such places. In some of these cases however the great height may be partly due to the cause mentioned at the end of the last paragraph.

When the tide-wave is propagated up a broad channel, which becomes shallow towards the sides, the motion of the water in the centre will be of the same nature as the motion in a free canal, so that the water will be flowing up the channel with its greatest velocity at the time of high water. Towards the coasts however there will be a considerable flow of water to and from the shore; and as far as regards this motion, the shore will have nearly the same effect as a barrier in a canal, and the oscillation will be of the nature of a stationary wave, so that the water will be at rest when it is at its greatest height. If, now, we consider a point at some distance from the shore, but still not near the middle of the channel, the velocity of the water up and down the channel will be connected with its height in the same way as in the case of a progressive wave, while the velocity to and from the shore will be connected with the height of the water in the same way as in a stationary wave. Combining these considerations, Mr. Airy is enabled to explain the apparent rotation of the water in such localities, which arises from an actual rotation in the direction of its motion*.

When the motion of the water is in two dimensions the mathematical calculation of the tidal oscillations is tolerably simple, at least when the depth of the water is uniform. But in the case of nature the motion is in three dimensions, for the water is distributed over the surface of the earth in broad sheets, the boundaries of which are altogether irregular. On this account a complete theory of the tides appears hopeless, even in the case in which the depth is supposed uniform. Laplace's theory, in which the whole earth is supposed to be covered with water, the depth of which follows a very peculiar law, gives us no idea of the effect of the limitation of the ocean by continents. Mr. Airy consequently investigates the motion of the water on the supposition of its being confined to narrow canals of uniform depth, which in the calculation are supposed circular. The case in which the canal forms a great circle is especially considered. This method enables us in some degree to estimate the effect of the boundaries of the sea; and it has the great advantage of leading to calculations which can be worked out. There can be no doubt, too, that the conclusions arrived at will apply, *as to their general nature*, to the actual case of the earth.

With a view to this application of the theory, Mr. Airy calculates the motion of the water in a canal when it is under the action of a disturbing force, which is a periodic function of the time. The disturbing force at a point whose abscissa, measured along the canal from a fixed point, is x, is supposed to be expressed by a function of the form $A \sin (nt - mx + \alpha)$. This supposition is sufficiently general for the case of the tides, provided the

* Art. 360, &c.

canal on the earth be supposed circular. In all cases the disturbing force will give rise to an oscillation in the water having the same period as the force itself. This oscillation is called by Mr. Airy a *forced wave*. It will be sufficient here to mention some of the results of this theory as applied to the case of the earth.

In all cases the expression for the tidal elevation contains as a denominator the difference of the squares of two velocities, one the velocity of propagation of a free wave along the canal, the other the velocity with which a particular phase of the disturbing force travels along the canal, or, which is the same, the velocity of propagation of the forced wave. Hence the height of the tides will not depend simply on the *magnitude* of the disturbing force, but also on its *period*. Thus the mass of the moon cannot be inferred *directly* from the comparison of spring and neap tides, since the heights of the solar and lunar tides are affected by the different motions of the sun and moon in right ascension, and consequently in hour-angle. When the canal under consideration is equatorial the diurnal tide vanishes. The height of high water is the same at all points of the canal, and there is either high or low water at the point of the canal nearest to the attracting body, according as the depth of the water is greater or less than that for which a free wave would be propagated with the same velocity as the forced wave. In the general case there is both a diurnal and a semidiurnal tide, and the height of high water, as well as the interval between the transit of the attracting body over the meridian of the place considered and the time of high water, is different at different points of the canal. When the canal is a great circle passing through the poles, the tide-wave is a stationary wave. When the coefficient of the disturbing force is supposed to vary slowly, in consequence of the change in declination, &c. of the disturbing body, it is found that the greatest tide occurs on the day on which the disturbing force is the greatest.

The preceding results have been obtained on the supposition of the absence of all friction; but Mr. Airy also takes friction into consideration. He supposes it to be represented by a horizontal force, acting uniformly from top to bottom of the water, and varying as the first power of the horizontal velocity. Of course this supposition is not exact: still there can be no doubt that it represents generally the effect of friction. When friction is taken into account, the denominator of the expressions for the tidal elevation is essentially positive, so that the motion can never become infinite. In the case of a uniform tidal river stopped by a barrier, the high water is no longer simultaneous at all points, but the phase of high water always travels up the river. But of all the results obtained by considering friction, the most important appears to be, that when the slow variation of the disturbing force is taken into account, the greatest tide, instead of happening on the day when the disturbing force is greatest, will happen later by a certain time, ρ_1. Moreover, in calculating the tides, we must use, not the relative positions of the sun and moon for the instant for which the tide is calculated, but their relative positions for a time earlier by the same interval ρ_1 as in the preceding case. The expression for ρ_1 depends both on the depth of the canal and on the period of the tide, and therefore its value for the diurnal tide cannot be inferred from its value for the semidiurnal. It appears also that the phase of the tide is accelerated by friction.

The mechanical theory of the tides of course belongs to hydrodynamics; but I do not conceive that the consideration of the reduction and discussion of tidal observations falls within the province of this report.

Before leaving the investigations of Mr. Airy, I would call attention to a method which he sometimes employs very happily in giving a general expla-

nation of phænomena depending on motions which are too complicated to admit of accurate calculation. It is evident that any arbitrary motion may be assigned to a fluid, (with certain restrictions as to the absence of abruptness,) provided we suppose certain forces to act so as to produce them. The values of these forces are given by the equations of motion. In some cases the forces thus obtained will closely resemble some known forces; while in others it will be possible to form a clear conception of the kind of motion which must take place in the absence of such forces. For example, supposing that there is propagated a series of oscillatory waves of the standard kind, except that the height of the waves increases proportionably to their distance from a fixed line, remaining constant at the same point as the time varies, Mr. Airy finds for the force requisite to maintain such a motion an expression which may be assimilated to the force which wind exerts on water. This affords a general explanation of the increase in the height of the waves in passing from a windward to a lee shore*. Again, by supposing a series of waves, as near the standard kind as circumstances will admit, to be propagated along a canal whose depth decreases slowly, and examining the force requisite to maintain this motion, he finds that a force must be applied to hold back the heads of the waves. In the absence, then, of such a force the heads of the waves will have a tendency to shoot forwards. This explains the tendency of waves to break over a sunken shoal or along a sloping beach†. The word *tendency* is here used, because when a wave comes at all near breaking, but little reliance can be placed in any investigation which depends upon the supposition of the motion being small. To take one more example of the application of this method, by supposing a wave to travel, unchanged in form, along a canal, with a velocity different from that of a free wave, and examining the force requisite to maintain such a motion, Mr. Airy is enabled to give a general explanation of some very curious circumstances connected with the motion of canal boats‡, which have been observed by Mr. Russell.

III. In the 16th volume of the 'Journal de l'Ecole Polytechnique§, will be found a memoir by MM. Barré de Saint-Venant and Wantzel, containing the results of some experiments on the discharge of air through small orifices, produced by considerable differences of pressure. The formula for the velocity of efflux derived from the theory of steady motion, and the supposition that the mean pressure at the orifice is equal to the pressure at a distance from the orifice in the space into which the discharge takes place, leads to some strange results of such a nature as to make us doubt its correctness. If we call the space from which the discharge takes place the *first* space, and that into which it takes place the *second* space, and understand by the term *reduced velocity* the velocity of efflux diminished in the ratio of the density in the second space to the density in the first, so that the reduced velocity measures the rate of discharge, provided the density in the first space remain constant, it follows from the common formula that the reduced velocity vanishes when the density in the second space vanishes, so that a gas cannot be discharged into a vacuum. Moreover, if the density of the first space is given, the reduced velocity is a maximum when the density in the second space is rather more than half that in the first. The results remain the same if we take account of the contraction of the vein, and they are not materially altered if we take into account the cooling of the air by its rapid dilatation. The experiments above alluded to were made by allowing the air to enter an exhausted receiver through a small orifice, and observing simultaneously the

* Art. 265, &c. † Art. 238, &c.
‡ Art. 405, &c. § Cahier xxvii. p. 85.

pressure and temperature of the air in the receiver, and the time elapsed since the opening of the orifice. It was found that when the exhaustion was complete the reduced velocity had a certain value, depending on the orifice employed, and that the velocity did not sensibly change till the pressure of the air in the receiver became equal to about $\frac{1}{2}$ths of the atmospheric pressure. The reduced velocity then began to decrease, and finally vanished when the pressure of the air in the receiver became equal to the atmospheric pressure.

These experiments show that when the difference of pressure in the first and second spaces is considerable, we can by no means suppose that the mean pressure at the orifice is equal to the pressure at a distance in the second space, nor even that there exists a contracted vein, at which we may suppose the pressure to be the same as at a distance. The authors have given an empirical formula, which represents very nearly the reduced velocity, whatever be the pressure of the air in the space into which the discharge takes place.

The orifices used in these experiments were generally about one millimetre in diameter. It was found that widening the mouth of the orifice, so as to make it funnel-shaped, produced a much greater proportionate increase of velocity when the velocity of efflux was small than when it was large. The authors have since repeated their experiments with air coming from a vessel in which the pressure was four atmospheres: they have also tried the effect of using larger orifices of four or five millimetres diameter. The general results were found to be the same as before*.

IV. In the 6th volume of the Transactions of the Cambridge Philosophical Society, p. 403, will be found a memoir by Mr. Green on the reflection and refraction of sound, which is well-worthy of attention. This problem had been previously considered by Poisson in an elaborate memoir†. Poisson treats the subject with extreme generality, and his analysis is consequently very complicated. Mr. Green, on the contrary, restricts himself to the case of plane waves, a case evidently comprising nearly all the phænomena connected with this subject which are of interest in a physical point of view, and thus is enabled to obtain his results by a very simple analysis. Indeed Mr. Green's memoirs are very remarkable, both for the elegance and rigour of the analysis, and for the ease with which he arrives at most important results. This arises in a great measure from his divesting the problems he considers of all unnecessary generality: where generality is really of importance he does not shrink from it. In the present instance there is one important respect in which Mr. Green's investigation is more general than Poisson's, which is, that Mr. Green has taken the case of any two fluids, whereas Poisson considered the case of two elastic fluids, in which equal condensations produce equal increments of pressure. It is curious, that Poisson, forgetting this restriction, applied his formulæ to the case of air and water. Of course his numerical result is altogether erroneous. Mr. Green easily arrives at the ordinary laws of reflection and refraction. He obtains also a very simple expression for the intensity of the reflected sound. If A is the ratio of the density of the second medium to that of the first, and B the ratio of the cotangent of the angle of refraction to the cotangent of the angle of incidence, then the intensity of the reflected sound is to the intensity of the incident as $A - B$ to $A + B$. In this statement the intensity is supposed to be measured by the first power of the maximum displacement. When the velocity of propagation in the first medium is less than in the second, and the angle of incidence exceeds what may be called the critical angle, Mr. Green restricts himself to the case of vibrations following the cycloidal law. He

* Comptes Rendus, tom. xvii. p. 1140.

† Mémoires de l'Académie des Sciences, tom. x. p. 317.

finds that the sound suffers total internal reflection. The expression for the disturbance in the second medium involves an exponential with a negative index, and consequently the disturbance becomes quite insensible at a distance from the surface equal to a small multiple of the length of a wave. The phase of vibration of the reflected sound is also accelerated by a quantity depending on the angle of incidence. It is remarkable, that when the fluids considered are ordinary elastic fluids, or rather when they are such that equal condensations produce equal increments of pressure, the expressions for the intensity of the reflected sound, and for the acceleration of phase when the angle of incidence exceeds the critical angle, are the same as those given by Fresnel for light polarized in a plane perpendicular to the plane of incidence.

V. Not long after the publication of Poisson's memoir on the simultaneous motions of a pendulum and of the surrounding air*, a paper by Mr. Green was read before the Royal Society of Edinburgh, which is entitled 'Researches on the Vibration of Pendulums in Fluid Media†.' Mr. Green does not appear to have been at that time acquainted with Poisson's memoir. The problem which he has considered is one of the same class as that treated by Poisson. Mr. Green has supposed the fluid to be incompressible, a supposition, however, which will apply without sensible error to air, in considering motions of this sort. Poisson regarded the fluid as elastic, but in the end, in adapting his formula to use, he has neglected as insensible the terms by which the effect of an elastic differs from that of an inelastic fluid. The problem considered by Mr. Green is, however, in one respect much more general than that solved by Poisson, since Mr. Green has supposed the oscillating body to be an ellipsoid, whereas Poisson considered only a sphere. Mr. Green has obtained a complete solution of the problem in the case in which the ellipsoid has a motion of translation only, or in which the small motion of the fluid due to its motion of rotation is neglected. The result is that the resistance of the fluid will be allowed for if we suppose the mass of the ellipsoid increased by a mass bearing a certain ratio to that of the fluid displaced. In the general case this ratio depends on three transcendental quantities, given by definite integrals. If, however, the ellipsoid oscillates in the direction of one of its principal axes, the ratio depends on one only of these transcendents. When the ellipsoid passes into a spheroid, the transcendents above-mentioned can be expressed by means of circular or logarithmic functions. When the spheroid becomes a sphere, Mr. Green's result agrees with Poisson's. It is worthy of remark, that Mr. Green's formula will enable us to calculate the motion of an ellipse or circle oscillating in a fluid, in a direction perpendicular to its plane, since a material ellipse or circle may be considered as a limiting form of an ellipsoid. In this case, however, the motion would probably have to be extremely small, in order that the formula should apply with accuracy.

In a paper 'On the Motion of a small Sphere acted on by the Vibrations of an Elastic Medium,' read before the Cambridge Philosophical Society in April 1841‡, Prof. Challis has considered the motion of a ball pendulum, retaining in his solution small quantities to the second order. The principles adopted by Prof. Challis in the solution of this problem are at variance with those of Poisson, and have given rise to a controversy between him and Mr. Airy, which will be found in the 17th, 18th and 19th volumes of the Philosophical

* Mémoires de l'Académie des Sciences, tom. xi. p. 521.

† This paper was read in December 1833, and is printed in the 13th volume of the Society's Transactions, p. 54, &c.

‡ Transactions of the Cambridge Philosophical Society, vol. vii. p. 333.

Magazine (New Series). In the paper just referred to, Prof. Challis finds that when the fluid is incompressible there is no decrement in the arc of oscillation, except what arises from friction and capillary attraction. In the case of air there is a slight theoretical decrement; but it is so small that Prof. Challis considers the observed decrement to be mainly owing to friction. This result follows also from Poisson's solution. Prof. Challis also finds that a small sphere moving with a uniform velocity experiences no resistance, and that when the velocity is partly uniform and partly variable, the resistance depends on the variable part only. The problem, however, referred to in the title of this paper, is that of calculating the motion of a small sphere situated in an elastic fluid, and acted on by no forces except the pressure of the fluid, in which an indefinite series of plane condensing and rarefying waves is supposed to be propagated. This problem is solved by the author on principles similar to those which he has adopted in the problem of an oscillating sphere. The views of Prof. Challis with respect to this problem, which he considers a very important one, are briefly stated at the end of a paper published in the Philosophical Magazine*.

In a paper 'On some Cases of Fluid Motion,' published in the Transactions of the Cambridge Philosophical Society†, I have considered some modifications of the problem of the ball pendulum, adopting in the main the principles of Poisson, of the correctness of which I feel fully satisfied, but supposing the fluid incompressible from the first. In this paper the effect of a distant rigid plane interrupting the fluid in which the sphere is oscillating is given to the lowest order of approximation with which the effect is sensible. It is shown also that when the ball oscillates in a concentric spherical envelope, the effect of the resistance of the fluid is to add to the mass of the sphere a mass equal to $\frac{b^3+2a^3}{b^3-a^3}\frac{m}{2}$, where a is the radius of the ball, b that of the envelope, and m the mass of the fluid displaced. Poisson, having reasoned on the very complicated case of an elastic fluid, had come to the conclusion that the envelope would have no effect.

One other instance of fluid motion contained in this paper will here be mentioned, because it seems to afford an accurate means of comparing theory and experiment in a class of motions in which they have not hitherto been compared, so far as I am aware. When a box of the form of a rectangular parallelepiped, filled with fluid and closed on all sides, is made to perform small oscillations, it appears that the motion of the box will be the same as if the fluid were replaced by a solid having the same mass, centre of gravity, and principal axes as the solidified fluid, but different principal moments of inertia. These moments are given by infinite series, which converge with extreme rapidity, so that the numerical calculation is very easy. The oscillations most convenient to employ would probably be either oscillations by torsion, or bifilar oscillations.

VI. M. Navier was, I believe, the first to give equations for the motion of fluids without supposing the pressure equal in all directions. His theory is contained in a memoir read before the French Academy in 1822‡. He considers the case of a homogeneous incompressible fluid. He supposes such a fluid to be made up of ultimate molecules, acting on each other by forces which, when the molecules are at rest, are functions simply of the distance, but which, when the molecules recede from, or approach to each other, are modified by this circumstance, so that two molecules repel each other less strongly when they are receding, and more strongly when they are approaching,

* Vol. xviii. New Series, p. 481. † Vol. viii. p. 105.

‡ Mémoires de l'Académie des Sciences, tom. vi. p. 389.

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than they do when they are at rest*. The alteration of attraction or repulsion is supposed to be, for a given distance, proportional to the velocity with which the molecules recede from, or approach to each other; so that the mutual repulsion of two molecules will be represented by $f(r) - \mathrm{V}\,\mathrm{F}(r)$, where r is the distance of the molecules, V the velocity with which they recede from each other, and $f(r)$, $\mathrm{F}(r)$ two unknown functions of r depending on the molecular force, and as such becoming insensible when r has become sensible. This expression does not suppose the molecules to be necessarily receding from each other, nor their mutual action to be necessarily repulsive, since V and $\mathrm{F}(r)$ may be positive or negative. It is not absolutely necessary that $f(r)$ and $\mathrm{F}(r)$ should always have the same sign. In forming the equations of motion M. Navier adopts the hypothesis of a symmetrical arrangement of the particles, or at least, which leads to the same result, neglects the irregular part of the mutual action of neighbouring molecules. The equations at which he arrives are those which would be obtained from the common equations by writing $\frac{dp}{dx} - \mathrm{A}\left(\frac{d^2u}{dx^2} + \frac{d^2u}{dy^2} + \frac{d^2u}{dz^2}\right)$ in place of $\frac{dp}{dx}$ in the first, and making similar changes in the second and third. A is here an unknown constant depending on the nature of the fluid.

The same subject has been treated on by Poisson†, who has adopted hypotheses which are very different from those of M. Navier. Poisson's theory is of this nature. He supposes the time t to be divided into n equal parts, each equal to τ. In the first of these he supposes the fluid to be displaced in the same manner as an elastic solid, so that the pressures in different directions are given by the equations which he had previously obtained for elastic solids. If the causes producing the displacement were now to cease to act, the molecules would very rapidly assume a new arrangement, which would render the pressure equal in all directions, and while this re-arrangement was going on, the pressure would alter in an unknown manner from that belonging to a displaced elastic solid to the pressure belonging to the fluid in its new state. The causes of displacement are however going on during the second interval τ; but since these different small motions will take place independently, the new displacement which will take place in the second interval τ will be the same as if the molecules were not undergoing a re-arrangement. Supposing now n to become infinite, we pass to the case in which the fluid is continually beginning to be displaced like an elastic solid, and continually re-arranging itself so as to make the pressure equal in all directions. The equations at which Poisson arrived are, in the cases of a homogeneous incompressible fluid, and of an elastic fluid in which the change of density is small, those which would be derived from the common equations by replacing $\frac{dp}{dx}$ in the first by

$$\frac{dp}{dx} - \mathrm{A}\left(\frac{d^2u}{dx^2} + \frac{d^2u}{dy^2} + \frac{d^2u}{dz^2}\right) - \mathrm{B}\frac{d}{dx}\left(\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz}\right),$$

and making similar changes in the second and third. In these equations A and B are two unknown constants. It will be observed that Poisson's equations reduce themselves to Navier's in the case of an incompressible fluid.

The same subject has been considered in a quite different point of view by M. Barré de Saint-Venant, in a communication to the French Academy in

* This idea appears to have been borrowed from Dubuat. See his Principes d'Hydraulique, tom. ii. p. 60.

† Journal de l'Ecole Polytechnique, tom. xiii. cah. 20. p. 139.

1843, an abstract of which is contained in the 'Comptes Rendus*.' The principal difficulty is to connect the oblique pressures in different direction about the same point with the differential coefficients $\frac{du}{dx}, \frac{du}{dy}$, &c., which express the relative motion of the fluid particles in the immediate neighbourhood of that point. This the author accomplishes by assuming that the tangential force on any plane passing through the point in question is in the direction of the principal sliding (*glissement*) along that plane. The sliding along the plane xy is measured by $\frac{dw}{dx} + \frac{du}{dz}$ in the direction of x, and $\frac{dw}{dy} + \frac{dv}{dz}$ in the direction of y. These two slidings may be compounded into one, which will form the principal sliding along the plane xy. It is then shown, by means of M. Cauchy's theorems connecting the pressures in different directions in any medium, that the tangential force on any plane passing through the point considered, resolved in any direction in that plane is proportional to the sliding along that plane resolved in the same direction so that if T represents the tangential force, referred to a unit of surface, and S the sliding, $T = \varepsilon S$. The pressure on a plane in any direction is then found. This pressure is compounded of a normal pressure, alike in all directions, and a variable oblique pressure, the expression for which contains the one unknown quantity ε. If the fluid be supposed incompressible, and ε constant, the equations which would be obtained by the method of M. Barré de Saint-Venant agree with those of M. Navier. It will be observed that this method does not require the consideration of ultimate molecules at all.

When the motion of the fluid is very small, Poisson's equations agree with those given by M. Cauchy for the motion of a solid entirely destitute of elasticity†, except that the latter do not contain the pressure p. These equations have been obtained by M. Cauchy without the consideration of molecules. His method would apply, with very little change, to the case of fluids.

In a paper read last year before the Cambridge Philosophical Society‡, I have arrived at the equations of motion in a different manner. The method employed in this paper does not necessarily require the consideration of ultimate molecules. Its principal feature consists in eliminating from the relative motion of the fluid about any particular point the relative motion which corresponds to a certain motion of rotation, and examining the nature of the relative motion which remains. The equations finally adopted in the case of a homogeneous incompressible fluid, and of an elastic fluid in which the change of density is small, agree with those of Poisson, provided we suppose in the latter $A = 3B$. It is shown that this relation between A and B may be obtained on Poisson's own principles.

The equations hitherto considered are those which must be satisfied at any point in the interior of the fluid mass; but there is hardly any instance of the practical application of the equations, in which we do not want to know also the particular conditions which must be satisfied at the surface of the fluid. With respect to a free surface there can be little doubt: the condition is simply that there shall be no tangential force on a plane parallel to the surface, taken immediately within the fluid. As to the case of a fluid in contact with a solid, the condition at which Navier arrived comes to this that if we conceive a small plane drawn within the fluid parallel to the sur-

* Tom. xvii. p. 1240.

† Exercices de Mathématiques, tom. iii. p. 187.

‡ Transactions of the Cambridge Philosophical Society, vol. viii. p. 287.

face of the solid, the tangential force on this plane, referred to a unit of surface, shall be in the same direction with, and proportional to the velocity with which the fluid flows past the surface of the solid. The condition obtained by Poisson is essentially the same.

Dubuat stated, as a result of his experiments, that when the velocity of water flowing through a pipe is less than a certain quantity, the water adjacent to the surface of the pipe is at rest*. This result agrees very well with an experiment of Coulomb's. Coulomb found that when a metallic disc was made to oscillate very slowly in water about an axis passing through its centre and perpendicular to its plane, the resistance was not altered when the disc was smeared with grease; and even when the grease was covered with powdered sandstone the resistance was hardly increased†. This is just what one would expect on the supposition that the water close to the disc is carried along with it, since in that case the resistance must depend on the internal friction of the fluid; but the result appears very extraordinary on the supposition that the fluid in contact with the disc flows past it with a finite velocity. It should be observed, however, that this result is compatible with the supposition that a thin film of fluid remains adhering to the disc, in consequence of capillary attraction, and becomes as it were solid, and that the fluid in contact with this film flows past it with a finite velocity. If we consider Dubuat's supposition to be correct, the condition to be assumed in the case of a fluid in contact with a solid is that the fluid does not move relatively to the solid. This condition will be included in M. Navier's, if we suppose the coefficient of the velocity when M. Navier's condition is expressed analytically, which he denotes by E, to become infinite. It seems probable from the experiments of M. Girard, that the condition to be satisfied at the surface of fluid in contact with a solid is different according as the fluid does or does not moisten the surface of the solid.

M. Navier has applied his theory to the results of some experiments of M. Girard's on the discharge of fluids through capillary tubes. His theory shows that if we suppose E to be finite, the discharge through extremely small tubes will depend only on E, and not on A. The law of discharge at which he arrives agrees with the experiments of M. Girard, at least when the tubes are extremely small. M. Navier explained the difference observed by M. Girard in the discharge of water through tubes of glass and tubes of copper of the same size by supposing the value of E different in the two cases. This difference was explained by M. Girard himself by supposing that a thin film of fluid remains adherent to the pipe, in consequence of molecular action, and that the thickness of this film differs with the substance of which the tube is composed, as well as with the liquid employed‡. If we adopt Navier's explanation, we may reconcile it with the experiments of Coulomb by supposing that E is very large, so that unless the fluid is confined in a very narrow pipe, the results will depend mainly on A, being sensibly the same as they would be if E were infinite.

There is one circumstance connected with the motion of a ball-pendulum oscillating in air, which has not yet been accounted for, the explanation of which seems to depend on this theory. It is found by experiment that the correction for the inertia of the air is greater for small than for large spheres, that is to say, the mass which we must suppose added to that of the sphere bears a greater ratio to the mass of the fluid displaced in the former, than in the latter case. According to the common theory of fluid motion, in which

* See the Table given in tom. i. of his Principes d'Hydraulique, p. 93.

† Mémoires de l'Institut, 1801, tom. iii. p. 286.

‡ Mémoires de l'Académie des Sciences, tom. i. pp. 203 and 234.

everything is supposed to be perfectly smooth, the ratio ought to be independent of the magnitude of the sphere. In the imperfect theory of friction in which the friction of the fluid on the sphere is taken into account, while the equal and opposite friction of the sphere on the fluid is neglected, it is shown that the arc of oscillation is diminished, while the time of oscillation is sensibly the same as before. But when the tangential action of the sphere on the fluid, and the internal friction of the fluid itself are considered, it is clear that one consequence will be, to speak in a general way, that a portion of the fluid will be dragged along with the sphere. Thus the correction for the inertia of the fluid will be increased, since the same moving force has now to overcome the inertia of the fluid dragged along with the sphere, and not only, as in the former case, the inertia of the sphere itself, and of the fluid pushed away from before it, and drawn in behind it. Moreover the additional correction for inertia must depend, speaking approximately, on the *surface* of the sphere, whereas the first correction depended on its *volume*, and thus the effect of friction in altering the time of oscillation will be more conspicuous in the case of small, than in the case of large spheres, other circumstances being the same. The correction for inertia, when friction is taken into account, will not, however, depend solely on the magnitude of the sphere, but also on the time of oscillation. With a given sphere it will be greater for long, than for short oscillations.

Sixth Report of a Committee, consisting of H. E. Strickland, *Esq.*, Prof. Daubeny, Prof. Henslow, *and* Prof. Lindley, *appointed to continue their Experiments on the Vitality of Seeds.*

These experiments have again been repeated upon 48 kinds of seeds gathered in 1843, as well as upon 26 kinds of new seeds added to the general collection in 1845.

Many kinds of old seeds, of various dates from 1812 to 1845 inclusive, consisting of 151 packets, have been contributed by Miss Molesworth. These were for the most part in small quantities, and were sown only at Oxford, on a slight hot-bed.

A small quantity of soil from the bed of a freshwater lake of the tertiary period, at Mundesley, Norfolk, containing scales of fish, elytra of beetles, seeds of *Ceratophyllum* and other plants from Sir W. C. Trevelyan, was subjected to three tests; viz. one-third part was placed in a shallow pan, and kept moist with distilled water; the second portion was kept well-saturated with the same; and the third portion, also in a shallow pan, under about one inch of distilled water. The whole was kept under a glass case to prevent the chance of seeds, &c. being deposited in it. No vegetation appeared in either case.

It may be well to remark, that the seeds have been sown under different circumstances, and have received different treatment at each of the three places they have been experimented upon. At Oxford, as in previous years, a selection was made from the whole quantity to be sown, of such as usually require the assistance of heat to enable them to germinate; these were sown in pots and placed in slight heat, and the remainder were sown on a small bed made in a cold frame, and, with the exception of two or three waterings, left to nature.

At Hitcham they were all sown in a border carefully prepared for them, and afterwards left to nature.

At Chiswick the whole of the seeds were sown in separate pots and placed in a pit heated with hot water.

These several treatments will at once account for the great difference there has been in many cases between the length of time the seeds required to vegetate, as well as the greater number of seeds which did vegetate at one place more than at the other, which will be seen on referring to the following statement of the results.

Name and Date when gathered.	No. sown.	No. of Seeds of each Species which vegetated at			Time of vegetating in days at			Remarks.
		Oxford.	Hitcham.	Chiswick.	Oxford.	Hitcham.	Chiswick.	
1843.								
1. Asphodelus luteus	50	6	2	24	28	33	12	
2. Arctium Lappa	100	9	1	54	18	.....	18	
3. Angelica Archangelica	100	.....	.....	47	.....	.....	20	
4. Ageratum mexicanum	200	1	.....	134	12	.....	20	
5. Aster tenella	200	8	.....	112	13	.....	20	
6. Allium fragrans	100	20	5	73	18	50	18	
7. Bidens diversifolia	150	.....	.....	124	.....	.....	20	
8. Biscutella erigerifolia	100	.....	2	69	.....	38	25	
9. Borkhausia rubra	100	69	84	43	4	7	20	
10. Bartonia aurea	200	11	8	141	18	21	16	
11. Callistemma hortensis	200	.....	.....	161	.....	.....	25	
12. Campanula Medium	100	31	3	76	18	27	16	
13. Centaurea depressa	100	5	1	43	17	28	20	
14. Cladanthus arabicus	200	26	.....	149	7	.....	20	
15. Cleome spinosa	100	5	1	55	30	.....	25	
16. Cnicus arvensis	.....	.....	.....	.....	.....	.....	.....	Bad in 1844.
17. Convolvulus major	50	6	2	33	11	39	12	
18. Dianthus barbatus	100	94	30	57	7	18	16	
19. Echium grandiflorum	100	49	19	67	6	13	25	
20. Eucharidium concinnum	200	67	12	177	6	18	18	
21. Euphorbia Lathyris	50	.....	1	45	.....	.....	25	
22. Gypsophila elegans	200	13	.....	130	11	.....	20	
23. Helenium Douglasii	200	45	24	117	5	12	25	
24. Hebenstreitia tenuifolia	100	26	4	72	6	15	16	
25. Heliophila araboides	200	16	.....	149	6	.....	20	
26. Hesperis matronalis	100	.....	.....	66	.....	.....	25	
27. Hypericum hirsutum	150	.....	.....	94	.....	.....	20	
28. Kaulfussia amelloides	100	26	6	82	7	16	16	
29. Koniga maritima	200	35	6	129	5	12	30	
30. Leptosiphon androsacea	200	2	.....	119	28	.....	20	
31. Lunaria biennis	100	37	3	74	16	29	25	
32. Loasa lateritia	150	.....	.....	112	.....	.....	30	
33. Mathiola annua	200	53	1	182	9	29	30	
34. Melilotus cærulea	100	46	42	61	4	6	25	
35. Œnanthe Crocata	100	22	1	42	37	56	30	
36. Phytolacca decandra	25	3	1	17	36	.....	34	
37. Plantago media	150	14	.....	116	16	.....	30	
38. Polemonium cæruleum	100	7	1	70	45	51	25	
39. Rumex obtusifolium	150	55	.....	107	17	.....	35	
40. Silene inflata	50	46	5	37	6	16	25	
41. Smyrnium Olusatrum	100	5	17	44	30	34	35	
42. Schizanthus pinnatus	200	69	23	148	5	14	25	
43. Tallinum ciliatum	200	12	.....	176	10	.....	35	
44. Tigridia Pavonia	100	12	.....	24	39	.....	35	
45. Valeriana officinalis	100	.....	.....	17	.....	.....	35	
46. Viola lutea vars	150	15	3	81	16	36	35	
47. Xeranthemum annuum	200	.....	.....	64	.....	.....	30	
48. Zinnia multiflora	150	.....	.....	37	.....	.....	20	

Name and Date when gathered.	No. sown.	No. of Seeds of each Species which vegetated at			Time of vegetating in days at			Remarks.
		Oxford.	Hitcham.	Chiswick.	Oxford.	Hitcham.	Chiswick.	
1845.								
49. Ailanthus glandulosa	50	20	7	36	32	51	25	
50. Alnus glutinosa	150	.....	.....	111	.....	.....	40	
51. Alonsoa incisa	100	.....	1	47	.....	.....	30	
52. Beta vulgaris	75	73	10	63	6	14	35	
53. Browallia elata	50	7	.....	39	40	.....	30	
54. Chrysanthemum coronarium	150	53	15	104	.....	12	20	
55. Cytisus albus	100	20	2	63	10	25	40	
56. Eccremocarpus scaber	100	.....	.....	41	.....	.....	30	
57. Fagus sylvatica	100	4	.....	76	110	.....	40	
58. Fumaria spicata	100	17	1	80	16	.....	20	
59. Gaillardia aristata	100	.....	.....	87	.....	.....	35	
60. Gleditschia triacanthos	20	.....	.....	.....	.....	.....		
61. Iris, sp.	25	.....	.....	14	.....	.....	35	
62. Knautia orientalis	50	6	4	29	12	18	30	
63. Lopezia racemosa	150	26	64	122	6	14	30	
64. Lymnanthes Douglasii	50	14	35	42	6	13	18	
65. Petunia odorata	150	10	.....	131	.....	.....	25	
66. Schizopetalon Walkeri	50	26	24	46	5	11	18	
67. Secale cereale	200	160	102*	194	5	11	25	
68. Spartium Scoparium	200	5	.....	117	.....	.....	40	
69. Tagetes lucida	150	.....	.....	139	.....	.....	20	
70. Verbena Aubletia	100	5	1	49	30	.....	25	
71. Viscaria oculata	150	.....	2	128	.....	10	20	
72. Xeranthemum annuum	100	.....	.....	77	.....	.....	25	
73. Zea Mays	100	98	9	91	7	22	35	
74. Zinnia grandiflora	100	.....	.....	86	.....	.....	25	

From Miss Molesworth:—

Name and Date.	No. sown.	No. vegetated.	Time of vegetating in days.	Name and Date.	No. sown.	No. vegetated.	Time of vegetating in days.
1812.				1828.			
1. Ricinus communis	12	0		15. Aster lactea	100	0	
1824.				16. Galium lucidum	8	0	
2. Catananche cærulea	100	0		17. Helianthemum croceum	100	0	
3. Cucurbita Citrullus	15	0		1829.			
1825.				18. Cucurbita, Cucuzza di Spagna	77	0	
4. Swiss Melon	5	0		19. —, Cucuzza Tiascheta	54	0	
1827.				20. Dorycnium monspeliense	100	0	
5. Brassica, white Cauliflower	100	0		21. Hypericum fimbriatum	100	0	
6. —, Brocoli di Carnivale	100	0		22. Milium	100	0	
7. —, — Primotice	100	0		23. Rumex alpinus	30	0	
8. —, Cavoli Feguti	100	0		1831.			
9. Cucurbita Citrullus	10	0		24. Cytisus leucanthus	100	0	
10. Melon	30	0		25. Genista candicans	16	0	
11. Green Melon	50	0		26. Sorghum vulgare	150	0	
12. Water Melon	30	0		27. Zea Mays	100	0	
13. Hypericum	150	0					
14. Spinacea Oleracea	50	0					

* At Hitcham, of 3 left, 2 did not flower, and the other produced no seed.

Name and Date.	No. sown.	No. vegetated.	Time of vegetating in days.
1832.			
28. Calendula, sp.	50	0	
29. Cucurbita Cucuzza	40	29	8
30. Green Egyptian Melon	40	3	7
31. Marari	29	8	
32. Gypsophila altissima	100	0	
33. Linaria genistifolia	100	0	
34. Phaseolus compressus	50	0	
35. Podalyria tinctoria	18	0	
1833.			
36. Cucurbita, Candahar Water Melon	50	0	
37. Cucuzza Lunga	5	0	
38. — di Spagna	20	11	7
39. Mellone di Acqua	90	8	10
40. — di Pane Bianca	50	2	7
41. — della Regina	50	0	
42. Orange Gourd	40	0	
43. Cucumber, Kabul	5	0	
1834.			
44. Catananche cærulea	200	0	
45. Coix lachryma	1	0	
46. Gourd	5	0	
47. Valencian Melon	50	20	5
48. Iris prismatica	10	0	
49. Pinus Pinea	19	3	?
50. Plantago bonariensis	100	0	
51. Sambucus racemosa	150	0	
52. Scrophularia grandiflora	200	0	
1835.			
53. Cucurbita	50	0	
54. Echinops, sp.	3	0	
55. Heracleum asperum	35	0	
56. Œnothera, sp.	200	0	
57. Orobus lathyroides	31	0	
58. Podalyria exaltata	36	0	
59. Tetragonia expansa	100	0	
60. Verbascum virgatum	50	0	
1836.			
61. Augusta Beans	2	0	
62. Cassia Canarina	10	1	42
63. Melon, early Cantalupe	72	50	7
64. —, from Lisbon	20	11	7
65. Cassia, sp.	40	0	
66. Euphorbia arkanocarpa	100	0	
67. — Characias	80	0	
68. Galega sibirica	110	9	7
69. Heracleum asperum	100	0	
70. Malva, sp.	80	6	30
71. From Malta	8	0	
72. Ditto	2	0	
73. Pepe	8	0	
74. Memoja	5	4	9
75. Œnothera, sp.	100	0	
76. Papaver somniferum	150	0	
77. Pyrethrum microphyllum	200	0	
78. Saponaria, sp.	100	0	
79. Tragopogon pratensis	88	0	
80. Aubergines	150	0	
81. Melon	150	50	5
82. Piments	100	0	
83. Tomates	100	76	6
1838.			
84. Anchusa ochroleuca	14	0	
85. Melon from Cassabah	15	11	7
86. Water Melon	10	0	
87. Melon from Valparaiso	5	0	
88. Cynoglossum, sp.	20	0	
89. Papaver somniferum	150	0	
90. Pinus nigricans	30	0	
91. Tragopogon, sp.	22	0	
92. ? Cassia	20	4	11
93. ? Dolichos	50	36	11
1839.			
94. Augusta Beans	50	24	10
95. Calliopsis	150	0	
96. Lapsana communis	100	0	
97. Lepidium Draba	50	0	
98. Pisum, sp.	50	36	8
99. Prunella vulgaris	150	0	
100. Ricinus communis	7	0	
101. Salvia verbenaca	200	0	
1840.			
102. Calliopsis tinctoria	150	3	36
103. Chenopodium Quinoa	200	0	
104. Canada Beans	50	42	10
105. Balsamina hortensis	150	81	7
106. Œnothera grandiflora	100	0	
107. Ornithogalum nutans	80	0	
108. Ricinus communis	10	0	
109. Salvia patens	12	0	
1841.			
110. Algoa Bay	1	0	
111. Canada Beans	16	16	9
112. Ferula, sp.	38	0	
113. Papaver somniferum	150	73	123
114. Physospermum commutatum	100	0	
115. Rumex, sp.	30	13	9
116. Salvia, sp.	150	0	
117. Vicia grandiflora	150	70	11
118. Fullard's German Marrow Fat	4	4	7
1842.			
119. Brassica, Rapa oleifera	100	85	4
120. Ervum, sp.	100	90	5
121. Gossypium ? vitifolium	8	2	8
122. Malva moschata	100	18	12
123. Melilotus macrorhiza	100	86	5
124. Papaver somniferum	150	0	
125. Phacelia tanacetifolia	150	50	5
126. Trifolium giganticum	190	0	
127. —, Alsike Clover	100	0	
128. Vicia sativa	100	82	7

Name and Date.	No. sown.	No. vegetated.	Time of vegetating in days.	Name and Date.	No. sown.	No. vegetated.	Time of vegetating in days.
1843.				1844.			
129. Cheiranthus, sp.....	80	38	7	141. Augusta Beans	5	5	8
130. Dianthus chinensis.....	150	62	8	142. Cobbett's Wheat	27	12	7
131. Diplotaxis tenuifolia ...	300	4	19	1845.			
132. Augusta Beans	30	30	9	143. Augusta Beans	30	27	8
133. Linum usitatissimum ...	200	56	7	144. Cobbett's Wheat	15	14	7
134. Melilotus leucantha ...	100	60	7	About 23 years old.			
135. Onopordon tauricum ...	150	22	10	145. Cashew Nut	4	0	
136. — acanthium.....	100	40	10	146. Brazil Nut	1	0	
137. Trifolium giganticum...	100	38	4	147. Longan	2	0	
138. —, Alsike Clover	100	0		148. Quercus, sp.	4	0	
139. Vicia lutea	100	27	31	149. — Ægilops.....	3	0	
140. Fullard's German Marrow Fat	150	100	7	150. Ricinus	5	0	
				151. Rhizobolus Pekæa	1	0	

W. H. Baxter, Curator.

On the Colouring Matters of Madder. *By* Dr. Schunck.

The organic colouring matters present such a wide field for inquiry, that i would require the labour of years to enable one person fully to elucidate thei properties, or even to bring this department of organic chemistry into a stat of development proportionate to the present condition of the science. Th substances included under the name of colouring matters by no means agre in their chemical characteristics; they merely coincide in being possessed o certain vivid colours, or in giving rise to coloured compounds. Strictly con sidered, some of them ought to be classed among the resins and others amon the extractive matters; and on the other hand, if we attempt a definition o the class according to their chemical characteristics, we shall find it impossibl to exclude a large number of bodies, which, like tannin and catechin, ar capable of giving rise under peculiar circumstances to brown substance which in nowise differ in their general properties from the bright red colou ing matters of archil, logwood, &c. Some colouring matters are presente to us ready formed in the different parts of plants and animals; others ar produced artificially from colourless substances, which undergo very comple changes during the process; others arise spontaneously during the first stage of oxidation or putrefaction following the extinction of organic life. In th investigation of substances thus widely differing in properties and formation it would be vain to expect at present anything approaching to general result in regard to the class as a whole. I must therefore content myself on thi occasion with giving a short account of the results of some experiment which I have made on one branch of the subject, at the same time apologisin for their present vague and undefined nature.

I have directed my attention in the first instance to madder, partly becaus the colouring matters contained in it are almost unknown, or rather wors than unknown, viz. known in such a manner as merely to mislead those wh wish to inform themselves by the accounts given of them, and partly becaus madder is an article of such an immense importance in the art of dyeing tha every discovery in relation to it acquires immediately a practical bearing.

It will be unnecessary for me to allude to the former numerous investiga

tions of madder, except so far as to mention that Robiquet discovered in it a crystallized volatile colouring matter, which he called *Alizarin*, and that Runge described five colouring matters which he obtained from it, viz. *madder purple, madder red, madder orange, madder yellow* and *madder brown*. I may here state as one result of my investigation, that I agree with Runge in thinking that there is more than one colouring matter in madder, though I am of opinion that the substances which he enumerates and describes are not pure. Before however entering on this part of the subject, I shall first give the results at which I have arrived in regard to alizarin. Alizarin is doubtless the most interesting and the most definite in its nature of all the substances contained in madder. It also presents itself the most easily to the observer even on the most superficial examination. If we heat madder spread out in a thin layer on a metal plate without carrying the heat far enough to char the woody parts of the root, we shall in the course of a few hours find its surface covered with small red or orange-coloured crystals, which consist of alizarin. In the same way any extract of madder, whether with water, alcohol or alkalies, evaporated to dryness and gently heated, gives a crystalline sublimate of alizarin, which is variously coloured from a light yellow to a dark red or brown. Now one of the first points to be ascertained in regard to this body was whether it exists as such in the root, or whether it is formed by the process of sublimation. Robiquet, the discoverer, states that it pre-exists in the plant. He considered alizarin as the colouring principle of madder, and merely subjected it to sublimation for the purpose of purifying it. But his investigation presents us with no convincing proof of this opinion, for the extract of madder with water, alcohol, &c., from which he prepares his alizarin by sublimation, shows no trace of anything crystalline; and many chemists have asserted in consequence that it is a product of decomposition, being formed by the action of heat in the same way as pyrogallic, pyrotartaric acid, and many other bodies. I have however no hesitation in affirming that it exists in the plant as such, having in more than one way obtained it in a crystallized state without the intervention of heat. If we make an extract of madder with cold water, we obtain a brown fluid which produces no reaction on test paper. After being exposed however to the action of the atmosphere for some hours, it acquires a distinctly acid reaction; and if it be now examined carefully, there will be found floating about in it a number of long hair-like shining crystals: these crystals are alizarin. If the fluid be still further exposed to the influence of the atmosphere, a yellow amorphous substance begins to separate, which I shall mention afterwards. This is succeeded by a gelatinous substance, and after some days a complete state of putrefaction ensues. It seems as if the alizarin in madder, or at all events that part which dissolves in the water, exists in combination with lime. On exposure to the atmosphere, there is formed, from some constituent of the root dissolved in the fluid through the instrumentality of the oxygen, some acid, which seizes hold of the lime in the solution and separates the bodies which are combined with the lime. Now the alizarin, being a body of very slightly acid properties, is separated first, and the other substances follow in succession. The fresher the madder is, the purer will be the alizarin, which separates on exposure to the atmosphere; in some instances it forms on the surface of the fluid a thick light yellow scum; but in most cases it is mixed with brown or red substances, from which it is separated with difficulty. It is therefore most advisable to separate the crystals which are deposited after twelve hours' standing, by filtration. These crystals are then washed from the filter and boiled with very dilute nitric acid until they have become of a bright yellow colour. They are then dissolved in boiling alcohol,

from which they separate on cooling in yellow transparent plates and needle having a strong lustre. Alizarin prepared in this way has the followin properties:—It has a pure yellow colour without any admixture of red. I may be volatilized without leaving any residue. The vapour crystallizes o cooling in beautiful yellow plates and needles. It suffers hardly any chang if exposed to the action of the most powerful reagents. It dissolves withou change in cold concentrated sulphuric acid. Concentrated nitric acid hardl affects it even on boiling. It is not changed by chlorine. It is insoluble i water, but soluble in alcohol with a yellow colour. It dissolves in alkalie with a beautiful purple colour. Its compounds with the alkaline earths ar red and slightly soluble in water. Its compounds with the earths and metalli oxides are insoluble in water and exhibit different shades of red. It impart no colour to cloth mordanted with acetate of alumina or oxide of iron, o account of its insolubility in water. Very little alizarin is obtained in thi way; perhaps one 1 gr. from 1 lb. of madder, though there is more of it cor tained in the root.

I shall now shortly describe two other colouring matters which I hav obtained from madder. If an extract of madder be made with hot or col water, and a strong acid, such as muriatic or sulphuric acid, be added to th fluid, a dark reddish-brown flocculent precipitate is produced. This prec pitate was separated by filtration and washed until the acid was removec On being treated with boiling water, a part of it dissolves with a brown colou On adding a few drops of acid to the filtered solution a dark brown pr cipitate is produced, which seems to me to be a peculiar colouring matte similar in its properties to orcein, hematin and other soluble colourin matters. It dissolves in alkalies with a red colour, and is capable of impartin very lively colours to mordanted cloth. As far as I am aware it has n been described in the former investigations of this subject, though it seen to be the principal substance concerned in the production of the colours fc which madder is used in the arts. I have however only examined it ver slightly as yet. The residue left behind by the boiling water was treate with dilute boiling nitric acid, by which every trace of the preceding substanc is destroyed, and the residue itself acquires a bright yellow colour an a more powdery consistence. This yellow powder contains alizarin, as shown by its giving crystals of that substance on being gently heated; i fact it contains all the alizarin of the root, but mixed with another substanc of an amorphous nature but very similar properties, from which it is difficu to separate it. By crystallising from alcohol no separation can be effecte as they are both about equally soluble in that menstruum. They also beha in a similar manner towards the alkalies, the earths and most of the metall oxides. I have hitherto only succeeded in discovering one method of s parating them, which is as follows:—The mixture of the two is dissolved in little caustic potash. To the solution is added perchloride of iron, whic produces a dark reddish-brown precipitate consisting of peroxide of iron i combination with the two substances. Now on boiling this precipitate wi an excess of perchloride of iron, the alizarate of iron dissolves, forming a da brown solution, while the iron compound of the other substance remai behind. On adding muriatic acid to the filtered solution, the alizarin separat in yellow flocks and may be purified by crystallization from alcohol. Th other substance, to which I have not yet given a name, is obtained by d composing its iron compound, which remains behind on treating with pe chloride of iron, with muriatic acid, and washing till all the oxide of iron removed. It seems also to be a colouring matter, as it dissolves with a re colour in alkalies and gives red compounds with the earths and metalli

oxides. It is insoluble in water, but soluble in alcohol with a yellow colour. It therefore resembles the resins in its general properties. It cannot be obtained in a crystallized state. From a hot concentrated solution in alcohol it separates on cooling as a yellow powder. It imparts no colour to mordanted cloth.

On the Physiological Action of Medicines. *By* J. Blake, *M.B., F.R.C.S.*

The present report is a continuation of those which have already been read before this section, and which have been published in the reports of the Association. The only additional experiments I now have to bring forward have been instituted to investigate the action of the salts of iridium and osmium, and the acids of selenium and sulphur, when introduced directly into the blood.

The experiments that have been made with the salts of iridium and osmium prove that these substances closely agree in their physiological action with the salts of palladium and platinum. They are, like these salts, very poisonous. A solution containing half a grain of the double chloride of iridium and ammonia, was injected into the jugular vein of a dog. Before the injection, the action of the heart was regular and strong*; in eight seconds after the injection, the action of the heart appeared affected, it being rendered fluttering; and after a few seconds there was an apparent obstacle to the passage of the blood through the systemic capillaries, as the pressure in the arterial system became greater. In about a minute the pressure again diminished; the action of the heart was slower, the force it exerted in propelling the blood being equal to a column of mercury of but three inches and a half, or little more than the half of that under which the circulation is generally carried on. The animal appeared to be uncomfortable, owing to the circulation becoming so feeble. On injecting a solution containing a grain of the salt, the circulation was arrested in eleven seconds, owing either to the action of the heart having ceased, or else that its contractions were so weakened that they did not suffice to force the blood through the pulmonary capillaries. The pressure exerted by the blood in the arterial system became suddenly diminished, so as only to support a column of mercury of an inch and a half, at which point the circulation through the capillaries would appear to have been suspended, for the pressure remained stationary for more than a minute, and then sunk to zero, owing to relaxation of the capillaries taking place. Death followed about three minutes and a half after the injection, and the eye retained its sensibility to mechanical irritation for three minutes; respiration and sensibility continuing nearly two minutes longer than would have been the case had the injection of the salt totally paralyzed the heart. On opening the thorax immediately after death, the heart was found contracting rythmically, but very feebly, certainly not with sufficient power to propel its contents: both cavities were full of blood; in the right it was dark, that in the left was of a maroon colour, and had evidently been oxygenized, proving that the circulation had ceased before respiration was suspended. The blood coagulated imperfectly, and this has been noticed after the introduction of the salts of palladium and platinum, which are isomorphous with those of

* The state of the circulation is ascertained by the hæmadynamometer, an instrument which enables us readily to detect any change in the action of the heart or in the passage of the blood through the systemic or pulmonary capillaries.

iridium, and which exert, although in such small quantities, a marked effect in preventing the perfect coagulation of the blood. Another experiment was performed to observe more particularly the general effects following the introduction of the salt into the veins; the hæmadynamometer was not used, and the animal was allowed to run about. On injecting a solution containing half a grain of the salt, no immediate effects followed, but in about forty seconds the animal became unsteady, and there was a tendency to fall backwards: in a minute and a half respiration was longer and deeper; sensibility remained unimpaired; after a few minutes the animal laid down, and the dyspnœa increased, coming on in paroxysms; in six minutes after the injection, respiration was suspended for forty seconds, but this was not accompanied by convulsions, or even by loss of sensibility: this occurred four or five times in the course of ten minutes; the animal laid perfectly still, and did not appear to be suffering, although sensibility was unimpaired. A grain of the salt, on being introduced into the vein, served to increase these symptoms, although the animal did not die until some minutes after it had been injected. These symptoms are such as would result from the gradual weakening of the action of the heart, and the consequent diminution of the supply of blood to the brain; they lead to the conclusion that, when injected into the veins, this salt does not exert any marked action on the nervous system. When introduced directly into the arteries, by being injected through the axillary artery so as to mix with the blood as it passes through the aorta, the salts of iridium, as those of platinum and palladium, impede the passage of the blood through the capillaries, to such an extent as to require the heart to exert more than twice the power that is required in the natural state of the circulation, to force the blood through them. This sudden increase of the pressure in the arterial system is attended by general spasm. When a grain of the salt was injected into the artery, in a few seconds the pressure was equal to a column of mercury of twelve inches; violent spasm immediately came on, during which respiration was suspended, nor did it again take place regularly. Six respiratory movements were observed during the next four minutes, after which there was no further movement. The action of the heart appeared to be arrested by asphyxia; but even after it had ceased, the pressure in the arteries was equal to three inches of mercury, showing that the passage of the blood through the systemic capillaries was still impeded, although the animal had been dead two or three minutes. When thus brought into direct contact with the nervous centres, there can be no doubt but that these substances exert a marked action on them; it is possible that the violent spasm that immediately followed their injection might be owing to the great pressure the brain is subject to from the over-distension of the arterial system, but this will not explain the permanent cessation of its functions.

The salts of osmium are perfectly analogous in their action to those of iridium, and the other members of this isomorphous group. The salt used was the double chloride of osmium and potassium, for owing to the chlorides of both iridium and osmium being decomposed by water, I was forced to use them combined with another base, although I should have wished to have avoided this if possible.

The effects produced by selenic and sulphuric acids, when introduced into the blood, are not very striking, that is, they do not appear to act in a marked manner on any one organ. They agree in this respect with other bodies, which either are found entering into the composition of the blood, or have isomorphous relations with these constituents. The important part which sulphur takes in the proteine compounds, might lead us to expect that its introduction into the blood, as well as selenium, which is so closely isomorphous

with it, might not produce any very marked effect. In an experiment performed with selenic acid, the following are the symptoms that presented themselves (the acid used was of specific gravity 1·046, containing about five and a half per cent. of real acid). On injecting three drachms of the acid, mixed with an equal quantity of water, into the jugular vein, no appreciable effect was produced; neither the passage of the blood through the lungs, nor through the systemic capillaries, appeared at all impeded; nor was the action of the heart affected; in about forty-five seconds after the injection its movements appeared slightly fluttering; after two minutes the respiration was observed to be rather deeper. Immediately after the introduction of half an ounce of the acid into the vein, there was a falling off of the quantity of blood sent into the arterial system; and as this took place five seconds after the injection, it must have been owing to the passage of the blood through the pulmonary capillaries having been impeded, for there had not been time for the substance to reach the coronary arteries and act on the heart. After thirty seconds the supply of blood to the arteries was restored, and the action of the heart was as strong as before. There appeared to be no marked effect produced on any organ, although the quantity of acid introduced was very considerable (seven drachms); after a few minutes the respiratory movements became longer and deeper, and the action of the heart decidedly weaker, the force with which the blood was propelled into the arteries being only half what it is in the natural state of the circulation; there was no expression of pain. Half an ounce of the acid was again injected into the veins. The immediate effect was to arrest the passage of the blood through the lungs, no blood being sent into the arteries, although the heart could be felt beating through the parietes of the thorax. Respiration was stopped at a minute and twenty seconds after the arrest of the circulation, sensibility having disappeared a few seconds earlier. On opening the thorax immediately after the cessation of respiratory movements, the heart was found beating rythmically: the right cavities were very much distended with blood, which was dark and grumous, and apparently physically incapable of passing through the lungs. The left cavities contained a small quantity of scarlet blood, which was coagulated; the lungs were redder than natural; the heart retained its irritability some time after death. The above symptoms do not suffice to indicate any particular organ on which the acid exerts a marked influence; for although death was produced by the passage of blood through the pulmonary capillaries being arrested, yet this was probably owing to the mechanical impediment which the coagulated state of the blood must have opposed to its passage through the pulmonary vessels. In other experiments that I have made with this substance, I have sometimes seen a serous secretion take place in the air passages. There is also some action on the nervous system, as the following experiment will show. The animal was small; it was not confined, in order that the effects on the functions of voluntary motion and sensation might be more accurately observed. A drachm of the acid was introduced into the veins, without giving rise to any marked symptoms. A second injection, containing a drachm and a half of the acid, did not affect the animal in any marked degree: after a few minutes it appeared rather dull, but there was no expression of pain, nor was sensibility impaired. On introducing two drachms into the veins, the animal fell down in about thirty seconds, and respiration was much affected; it got up again in about a minute, and jumped about in a very curious manner, the movements being evidently involuntary, as if the animal had chorea: it remained standing quite motionless for a few minutes, but gradually became weaker, and death took place ten minutes after the last injection; there were no convulsions, nor was the sensibility

destroyed until immediately before death. On opening the thorax, the heart was found contracting rythmically. There was a considerable quantity of frothy secretion in the bronchial tubes, and this renders it difficult to determine if the asphyxia, by which the action of the heart was finally arrested, was nervous or pulmonary; that is, whether the nervous system was affected by the want of aëration of the blood, or whether the respiratory movements ceased in consequence of the action of the acid directly on the nervous system. The latter opinion I think the more probable.

Sulphuric acid, when introduced into the veins, gives rise to exactly the same phænomena, the only organ on which it appears to exert any marked effect being the lungs, although slight nervous symptoms are produced when a considerable quantity has been introduced into the blood. The action of these substances when injected into the arteries, and thus applied directly to the brain and over the system, without previously passing through the lungs, is evidently on the nervous system. Two drachms of the diluted acid, mixed with four drachms of water, were injected into the left axillary artery, so as to pass into the aorta; in ten seconds all movements ceased; there was a slight spasm, which relaxed in a few seconds. During the continuance of the spasm, the pressure in the arterial system was slightly increased, but it rapidly declined, so that I think the passage of the blood through the systemic capillaries is facilitated, rather than impeded by these substances. All effective contractions of the heart ceased a minute after death, probably owing to the shock produced by the sudden annihilation of the functions of the nervous system, for it retained its irritability some minutes after death.

With these experiments I conclude the first part of the series of researches which I propose to undertake for the elucidation of this branch of physiology. I have been engaged on it for the last six years, but I trust the results obtained fully repay the labour that has been bestowed on it. The action on the animal œconomy of the compounds of twenty-nine of the most important elements has been experimentally investigated, and the facts which have been observed have led to the discovery of a new law in vital chemistry which had escaped the attention of former observers, viz. *that the reactions which take place between the elements of the living body and inorganic compounds are not governed by the ordinary chemical properties of these substances, but depend on certain properties they possess connected with their isomorphous relations.* The verification of this law enables us to undertake the investigation of the higher chemical phænomena of living bodies from an entirely new point of view, whilst its existence accounts for the failure that has constantly attended attempts to explain the chemistry of animal life by analogy from ordinary chemical phænomena. The fact that we now possess the means of producing well-marked and definite modifications of some of the most important physiological properties of various organs, and this too by means of reagents, the laws governing whose action we are acquainted with, places in our hands an instrument for discovery which has hitherto been wanting in physiological investigations. The enumeration of some of the effects that can be produced at pleasure on the more important functions, will, I trust, suffice to lead others into this rich field of inquiry. As regards the functions of the heart, we can annihilate or increase its irritability, quicken or diminish its pulsations, render them regular or irregular, augment their force or render them weaker, destroy the contractility of the auricles, whilst that of the ventricles remains; keep up the circulation of the blood many minutes after every sign of life has disappeared, and this too more actively than when respiration was being carried on; we can facilitate or arrest the passage of the blood through the pulmonary and systemic capil-

laries; produce important modifications in the functions of the brain:—in short, the injection of various substances into the arteries and veins enables us to modify all the most important functions of the body: and this, as before stated, by reagents, the laws of whose action we can fairly hope to discover. My reason for having neglected the closer investigation of these interesting phænomena, was a determination fully to establish the law of the analogous action of isomorphous substances. This having been accomplished, I shall now direct my researches to the elucidation of these secondary questions.

Report on the Actinograph. *By* Mr. Robert Hunt.

It will be remembered that in 1838 Sir John Herschel proposed an instrument for the purpose of registering the variations of the actinic or chemical rays, and published in the Philosophical Transactions a design for what he termed an Actinograph, by which it was thought both the chemical action of the direct solar rays and of the diffused daylight would be registered. Dr. Daubeny, Prof. Nichols and Mr. Thomas Jordan have severally designed, and I believe used, instruments somewhat similar, but it does not appear that any very satisfactory results have been obtained by either of these inquirers. At the York meeting I pointed out the importance of some such registration, and at the request of the committee I had an instrument constructed, which I exhibited to the Association at the Cambridge meeting. The actinograph I have been using differs but little from that proposed by Sir John Herschel, a modification of Mr. Jordan's being introduced, by which it was thought the results could be tabulated for every hour of the day. As the form of this instrument is published in the Report for 1845, it will be unnecessary to do more than describe such alterations as have suggested themselves during the past year. The triangular slit, divided into one hundred parts, has been abandoned, it being found in practice almost impossible to discriminate between the amount of coloration produced on the paper during an exposure of three minutes or six; consequently it became quite idle to attempt to register by this plan to the degree of nicety which it was hoped might be attained. A new external cylinder has therefore been constructed, in which are thirteen holes, commencing with a mere pin-hole and gradually increasing to a $\frac{1}{4}$ inch diameter. By this means thirteen bands are marked upon the sensitive paper, each one separated from the other by an unaltered line, and it becomes easy to distinguish with considerable accuracy between the tints thus produced.

Bromide of silver was the material which, from the circumstance that all the rays of the prismatic spectrum exert some influence upon it, was employed in procuring most of my registrations. It has however been found that under all circumstances this preparation is too sensitive, and that although in the winter, when the solar radiations are weak, it answers admirably, yet in the bright sunshine of summer it assumes too great a degree of darkness, in even diffused daylight, and during the shortest exposure to which it is exposed during the revolution of the cylinder. Many experiments have been made with other photographic preparations, and the result has been in favour of the general use of the ammonio-nitrate of silver. It is true that this paper is not impressed by all the rays of the spectrum, but, as it is acted upon by all the rays beyond the yellow ray, and as the influence of the actinic principle throughout the entire range of the spectrum is, as it appears, always equally

effected by the increased or diminished intensity of the luminous and calorific rays, and consequently that even the actinism residing in the extreme violet ray is relatively as much influenced by an increase of luminous power as that which is detected in the yellow ray itself, we may by the use of the paper prepared with the ammonio-nitrate of silver arrive at a very close approximation to the true result.

Although I have not been enabled to realize the hope I held forth last year of presenting at this meeting a register of actinic influences for the year, (which I have been prevented from doing by circumstances which I shall presently explain,) yet I have determined, most satisfactorily to my own mind, the practicability of procuring, in favourable positions, such a registration as shall afford much valuable information.

The circumstances to which I allude as those which have prevented my procuring any series of registers, are the impossibility of securing in London any position free from the constant interferences of smoke and fog, and the difficulty of placing the instrument so as to be free from the reflected radiations of adjoining buildings. The first alone is a fatal objection; for instead of securing, what is desired, a registration of the relative amount of chemical influence as compared with the quantity of light, heat, and the natural atmospheric conditions, we only get a register of the influence of smoke in absorbing the actinic rays. I therefore propose to hand over the instrument to the Association, requesting that it may be placed in a favourable position at Kew, under the attention of the excellent observer there, when I do not doubt some curious and instructive results may be obtained.

It is necessary however to state that my experience has pointed out some objections to this mode of registration, which indeed militates against the use of the actinograph as a philosophical instrument.

It is a curious fact that upon almost all kinds of photographic paper the colour produced by the solar rays at different periods of the day varies considerably. It is not a mere difference of tint, but an actual change in the colour; thus frequently the light of both morning and evening will give to chloride of silver a rose hue, whilst that of noon will change it to a bluish variety of brown. There is consequently much difficulty in deciding which is the strongest impression. Thus also the rays upon two days, when the sun appears equally bright, will in one case produce a red brown, and in the other a blue brown. It is left to the eye to decide upon the intensity of the effect produced, and with the utmost care it is frequently impossible to say whether the actinic influence is greatest on the red brown lines, or those which are blue brown.

The importance of the inquiry has been peculiarly evident during this summer; many peculiarities have been observed in the growth of plants, influenced no doubt by the solar radiations. Many of our garden flowers, particularly roses, have exhibited an abnormal condition, leaf-buds being developed in the centre of the flower, arising from the vegetative functions of the plant overpowering its reproductive functions. Again, during the intense sunshine and the prevalence of the unclouded skies of the hot weather of June and July, practical photographists found the greatest difficulty in obtaining portraits by the Daguerreotype process. At this time, although the intensity of effect produced on paper in the actinograph under the usual circumstances of summer sunlight should have been at a maximum, it was found that it was far below this point, the maximum point being represented by 120. During several experiments made at the time mentioned, the greatest effect indicated was 100; whilst the sky still being unclouded and the sun shining brightly, it often fell to 90, and sometimes indeed to 80.

These facts show the importance, amongst many others, of some mode of registration by which these ever-varying solar influences may be carefully observed. There can be little doubt that they exert an influence, sometimes baleful, sometimes beneficial, upon the organized creation, and that we have yet to discover, in these emanations or influences, the secrets of many of the grand phænomena of the universe.

Notices on the Influence of Light on the Growth of Plants.

By Mr. ROBERT HUNT.

THE experiments connected with this very interesting inquiry have been steadily pursued, and a concluding report would have been made at this meeting, but that some experiments, which had been conducted with much care, with a view of determining the quantity of solid matter in plants grown under different circumstances, were destroyed by the hail-storm which lately prevailed over an extensive district of the metropolis, the glasses and troughs of coloured fluids being broken, and the plants themselves washed into the soil. As it was impossible to repeat this year these experiments, there was no alternative but either to present an imperfect report, or to defer the report for another year. The latter course has been chosen, and the detail of these experiments will be reserved for a future communication; I have however thought it might be attended with some advantages to state a few of the leading facts which have been determined. The order of the arrangements have been the same as those observed in the former experiments, and nearly all the results have been confirmatory of those published six years since.

The germination of seeds is peculiarly due to the influence of the actinic or chemical rays; and if these are completely isolated whilst the luminous rays are permitted to act upon the soil in which the seeds are planted, no germination will take place. This influence is exerted and is most necessary up to the point at which the first leaves begin to form, when the luminous rays are rendered necessary to effect the formation of woody fibre. It must be remembered that this was a point upon which I was at issue with some other investigators; and it is due to them that I should state, that the discrepancies between us appear to have arisen from our not observing with a sufficient degree of accuracy the point at which the two influences balance each other, previously to the more complete exercise of the exciting force of light, as distinguished from actinism. The vegetative process having been carried on until the plant arrives at its maturity, a new agency, the calorific, is more decidedly necessary to develope the reproductive functions of the plant; and then, again, the chemical rays combined with the calorific become more active than the luminous rays. In spring we find the chemical influences exerting without interference their most decided force: seeds then germinate, and young buds and shoots are developed. As soon as this is effected, the luminous rays, with the advance of the sun, become more active, and the formation of woody fibre proceeds under their particular agency; not that the chemical power becomes dormant, but it is rendered proportionally less active by the agency of light. In the late summer and the autumn the peculiar properties of the calorific rays are required, and under their agency, with diminished powers of light, the ripening of fruits and the production of seed are accomplished.

My experiments have also led me to detect some curious influences which appear to be due to dissimilar rays, and which in their action exhibit great

inconstancy of effect. One class of rays, the same to which Sir J. Herschel has given the name of Parathermic rays, are so subdued by the influences of the more refrangible rays, as to be nearly inactive during the spring and early summer months; and indeed in the spring they scarcely produce any effect upon dead vegetable colouring matter, unless their action is assisted by the use of some decomposing agent, such as sulphuric acid. These rays increase in power towards the autumn, and to them appears to be due the browning of the leaf.

It is well known that plants will grow in the dark, but that they do not then form chlorophylle; the formation of this colouring-matter has been an object of some attention, and I believe I have determined it to result from the joint influence of the luminous and actinic rays. Boxes of cress have been grown in the dark, and they have then been brought under the influence of a large spectrum formed by a water-prism. It has been stated by Dr. Gardner, that the plants under those circumstances exhibit a lateral movement, bending towards the yellow ray. This appears to be a mistake; the plants under the influence of the red rays bend from the light but along the line of the ray; and those exposed to the most refrangible rays turn towards it, but still in the line of the ray. Now the plants which first become green, by careful treatment in this way, are those which are exposed to the rays situated between the mean green ray and the extreme blue. The action is continued eventually to the edge of the most refrangible violet below the yellow ray. There is not any change effected beyond the visible spectrum, notwithstanding the abundance of dark chemical rays; and the change is slow where there is really the largest amount of light. I therefore conclude that the luminous rays are essential in the process, producing the decomposition of the carbonic acid and the deposition of the required carbon, which is afterwards, in all probability, combined with hydrogen under the influence of purely chemical force as exerted by the actinic principle.

Such are the main results I have obtained. I have several experiments now in progress, and I hope to be enabled in another year to complete this particular branch of investigation so far as to present to the British Association a complete report.

Report on the Recent Progress of Analysis (Theory of the Comparison of Transcendentals). By R. L. Ellis, *M.A.*

1. The province of analysis, to which the theory of elliptic functions belongs, has within the last twenty years assumed a new aspect. A great deal has doubtless been effected in other subjects, but in no other I think has our knowledge advanced so far beyond the limits to which it was not long since confined.

This circumstance would give a particular interest to a history of the recent progress of the subject, even did it now appear to have reached its full development. But on the contrary, there is now more hope of further progress than at the commencement of the period of which I have been speaking. When, in 1827, Legendre produced the first two volumes of his 'Théorie des Fonctions Elliptiques,' he had been engaged on the subject for about forty years; he had reduced it to a systematic form; and had with great labour constructed tables to facilitate numerical applications of his results. But little more, as it seemed, was yet to be done; nor does the remark of

Bacon, that knowledge, after it has been systematized, is less likely to increase than before, seem less applicable to mathematical than to natural science. Nevertheless, almost immediately after the publication of Legendre's work, the earlier researches of Abel and Jacobi became known, and it was at once seen that what had been already accomplished formed but a part, and not a large one, of the whole subject.

To say this is not to derogate from the merit of Legendre. He created the theory of elliptic functions; and it is impossible not to admire the perseverance with which he devoted himself to it. The attention of mathematicians was given to other things, and though the practical importance of his labours was probably acknowledged, yet scarcely any one seems to have entered on similar researches*. This kind of indifference was doubtless discouraging, but not long before his death he had the satisfaction of knowing that there were some by whom that which he had done would not willingly be let die.

The considerations here suggested have led me to select the theory of the integrals of algebraical functions as the subject of the report which I have the honour to lay before the Association.

2. The theory of the comparison of transcendental functions appears to have originated with Fagnani. In 1714, he proposed, in the 'Giornale de Litterati d'Italia,' the following problem: To assign an arc of the parabola whose equation is

$$y = x^4,$$

such that its difference from a given arc shall be rectifiable.

Of this problem he gave a solution in the twentieth volume of the same journal.

The principle of the solution consists in the transformation of a certain differential expression by means of an algebraical and rational assumption which introduces a new variable. The transformed expression is of the same form as the original one, but is affected with a negative sign. By integrating both we are enabled to compare two integrals, neither of which can be assigned in a finite form. It is difficult, however, to perceive how Fagnani was led to make the assumption in question: a remark which applies more or less to his subsequent researches on similar subjects.

The theorem which has made his name familiar to all mathematicians, appeared in the twenty-sixth volume of the 'Giornale.' In its application to the comparison of hyperbolic arcs we find some indications of a more general method. We have here a symmetrical relation between two variables, x and z, such that the differential expression $f(x)\,dx$ may be written in the form $z\,dx$. It follows at once that $f(z)\,dz = x\,dz$, and consequently that

$$\int f(x)\,dx + \int f(z)\,dz = \int \{x\,dz + z\,dx\} = xz + \mathrm{C}.$$

The remarkable manner in which the idea of symmetry here presents itself, suggested to Mr. Fox Talbot his 'Researches in the Integral Calculus.'

In applying his methods to the division of the arc of the lemniscate, Fagnani obtained some very curious results, and has accordingly taken for the vignette of his collected works a figure of this curve with the singular motto, "Deo veritatis gloria."

3. In MacLaurin's Fluxions, and in the writings of D'Alembert, instances are to be found where the solution of a problem is made to depend on the

* Those of M. Gauss, which would doubtless have been exceedingly valuable, have not, I believe, been published. They are mentioned in a letter from M. Crelle to Abel. Vide the introduction to the collected works of the latter, p. vii.

rectification of elliptic arcs, or, as we should now express it, is reduced to elliptic integrals. But of these instances Legendre has remarked that they are isolated results, and form no connected theory. MacLaurin is charged, in a letter appended to the works of Fagnani, with taking from the latter, without acknowledgement, a portion of his discoveries with respect to the lemniscate and the elastic curve.

4. In 1761, Euler, in the 'Novi Commentarii Petropolitani' for 1758 and 1759, published his memorable discovery of the algebraical integral of the equation

$$\frac{m\,dx}{(A + Bx + Cx^2 + Dx^3 + Ex^4)^{\frac{1}{2}}} = \frac{n\,dy}{(A + By + Cy^2 + Dy^3 + Ey^4)^{\frac{1}{2}}},$$

m and n being any rational numbers.

He says he had been led to this result by no regular method, "sed id potius tentando, vel divinando elicui," and recommends the discovery of a direct method to the attention of analysts. In effect his investigations resemble those of Fagnani: he begins by assuming a symmetrical algebraical relation between the variables, and hence finds a differential equation which it satisfies. In this differential equation the variables are separated, so that each term may be considered as the differential of some function. With one form of assumed relation we are led to the differentials of circular, and with another to those of elliptic integrals, and so on. It is in this manner that Dr. Gudermann, in the elaborate researches which he has published in Crelle's Journal, has commenced the discussion of the theory of elliptic functions.

5. In the fourth volume of the Turin Memoirs, Lagrange accomplished the solution of the problem suggested by Euler. He integrated the general differential equation already mentioned by a most ingenious method, which, with certain modifications, has remained ever since an essential element of the theory of elliptic functions. He proceeded to consider the more general equation

$$\frac{dx}{\sqrt{X}} = \frac{dy}{\sqrt{Y}},$$

where X and Y are any similar functions of x and y respectively, and came to the conclusion, that if they are rational and integral functions, the equation cannot, except in particular cases, be integrated, if they contain higher powers than the fourth. He also integrated this equation in a case in which X and Y involve circular functions of the variables. It had been already pointed out in the summary of Euler's researches, given in the 'Nov. Com. Pet.' t. vi., that if X and Y are polynomials of the sixth degree, the last-written equation does not in general admit of an algebraical integral, since, if so, it would follow that the solution of the equation $\frac{dx}{1+x^3} = \frac{dy}{1+y^3}$, which (as the square of $1 + x^3$ is a polynomial of the sixth degree) is a particular case of that which we are considering, could be reduced to an algebraical form. Now this solution involves both circular functions and logarithms, and therefore the required reduction is impossible. This acute remark* showed that Euler's result did not admit of generalisation in the manner in which it was natural to attempt to generalise it. It was reserved for Abel to discover the direction in which generalisation is possible.

6. The discovery of Euler, of which we have been speaking, is in effect the foundation of the theory of elliptic functions, as the generalisation of it by Abel, or more properly speaking, the theory of which Euler's result is an

* M. Richelot, in one of his memoirs on Abelian or hyper-elliptic integrals, quotes it, in a slightly modified form, from Euler's 'Opuscula.'

isolated fragment, is the foundation of our knowledge of the higher transcendents. We may therefore conveniently divide the subject of this report into two portions, viz. the general theory of the comparison of algebraical integrals, and the investigations which are founded on it. Mathematicians have been led, by comparing different transcendents, to introduce new functions into analysis, and the theory of these functions has become an important subject of research.

The second portion may again be divided into two, viz. the theory of elliptic functions, and that of the higher transcendents.

This classification, though not perhaps unexceptionable, will, I think, be found convenient.

7. About sixteen years after the publication of Lagrange's earlier researches on the comparison of algebraical integrals, he gave, in the New Turin Memoirs for 1784 and 1785, a method of approximating to the value of any integral of the form $\int \frac{P\,dx}{R}$, where P is a rational function of x and R the square root of a polynomial of the fourth degree. I shall consider this important contribution to the theory of elliptic functions in connexion with the writings of Legendre. At present, in order to give a connected view of the first division of my subject, it will be necessary to go on at once to the works of Abel, and to those of subsequent writers. In the history of any branch of science the chronological order must be subordinate to that which is founded on the natural connexion of different parts of the subject.

I shall merely mention in passing, that in 1775, Landen published in the Philosophical Transactions a very remarkable theorem with respect to the arcs of a hyperbola. He showed that any arc of a hyperbola is equal to the difference of two elliptic arcs together with an algebraical quantity. In 1780 he published his researches on this subject in the first volume of his 'Mathematical Memoirs,' p. 23. This theorem, as Legendre has remarked, might have led him to more important results. It contains the germ of the general theory of transformation, the eccentricities of the two ellipses being connected by the modular equation of transformations of the second order*. It is on this account that in a report on M. Jacobi's 'Fundamenta Nova,' contained in the tenth volume of the Memoirs of the Institute, Poisson speaks of Landen's theorem as the first step made in the comparison of dissimilar elliptic integrals. Several writers have accordingly given Landen's name to the transformation commonly known as Lagrange's.

8. We have seen that even Lagrange failed in obtaining a result more general than that which had been made known by Euler, and yet, as we now know, Euler's theorem is but a particular case of a far more general proposition. But in order to further progress, it was necessary to introduce a wholly new idea. The resources of the integral calculus were apparently exhausted; Abel, however, was enabled to pass on into new fields of research, by bringing it into intimate connexion with another branch of analysis, namely, the theory of equations. The manner in which this was done shows that he was not unworthy to follow in the path of Euler and of Lagrange.

I shall attempt to state in a few words the fundamental idea of Abel's method.

Let us suppose that the variable x is a root of the algebraical equation $fx = 0$, and that the coefficients of this equation are rational functions of certain quantities $a, b, \ldots c$, which we shall henceforth consider independent variables. Let us suppose also that in virtue of this equation we can express

* Vide *infra*, pp. 50 and 67.

certain irrational functions* of x as rational functions of $x, a, b, \ldots c$. For instance, if the equation were $x^2 + ax + \frac{1}{2}(a^2 - 1) = 0$, it follows that $\sqrt{1-x^2} = a + x$. So that any irrational function of the form $F(x\sqrt{1-x^2})$ can be expressed rationally (F being rational) in x and a.

From the given equation we deduce by differentiation the following,

$$dx = \alpha\, da + \beta\, db + \ldots + \gamma\, dc,$$

where $\alpha, \beta, \ldots \gamma$ are rational in $x, a, b, \ldots, c$.

Let y be one of the functions which can be expressed rationally in x, &c., it follows that

$$y\, dx = A\, da + B\, db + \ldots + C\, dc,$$

where A, B, ... C are also rational in x, &c.

The equation $fx = 0$ will have a number of roots, which we shall call $x_1, x_2 \ldots x_\mu$. It follows that

$$y_1\, dx_1 + \ldots + y_\mu\, dx_\mu =$$

$$\{A_1 + \ldots + A_\mu\}\, da + \{B_1 + \ldots + B_\mu\}\, db + \ldots + \{C_1 + \ldots + C_\mu\}\, dc,$$

where the indices affixed to y, A, &c. correspond to those affixed to x, so that y_1, for instance, is the same function of x_1 that y_2 is of x_2.

Now $A_1 + \ldots + A_\mu$ is rational and symmetrical with respect to $x_1 \ldots x_\mu$, therefore it can be expressed rationally in the coefficients of $f(x) = 0$, and therefore in $a, b \ldots c$. We will call this sum R_a, and thus with a similar notation for b, &c. we get

$$y_1\, dx_1 + \ldots + y_\mu\, dx_\mu = R_a\, da + R_b\, db + \ldots + R_c\, dc.$$

The second side of this equation is from the nature of the case a complete differential, and it is rational in a, b, c, &c.; it can therefore be integrated by known methods; and if we denote $\int^{x_1} y\, dx$ by $\psi(x_1)$, we get

$$\psi(x_1) + \ldots + \psi(x_\mu) = M,$$

M being a logarithmic and algebraic function of a, b, &c., which we may suppose to include the constant of integration.

$\psi(x)$ is in general a transcendental function, while a, b, &c. are necessarily algebraical functions of $x_1, \ldots, x_\mu$, and the result at which we have arrived is therefore an exceedingly general formula for the comparison of transcendental functions.

The simplicity and generality of these considerations entitle them to especial attention: it cannot be doubted that the application thus made of the properties of algebraical equations to the comparison of transcendents will always be a remarkable point in the history of pure analysis.

A very simple example may perhaps illustrate what has been said. Let us recur to the equation

$$x^2 + ax + \frac{1}{2}(a^2 - 1) = 0, \quad \ldots\ldots\ldots \quad (1.)$$

and suppose that

$$y = \frac{1}{\sqrt{1-x^2}}.$$

Differentiating the first of these equations, we find that

$$(2x + a)\, dx + (x + a)\, da = 0.$$

* It must be remembered that an algebraical function is either explicit or implicit: explicit, when it can be expressed by a combination of ordinary algebraical symbols; implicit, when we can only define it by saying that it is a root of an algebraical equation whose coefficients are integral functions of x. Thus y is an implicit function of x if $y^5 + xy + 1 = 0$. The remarks in the text apply to all algebraical functions, explicit or implicit.

Comparing this with the general expression of dx, we perceive that

$$a = -\frac{x+a}{2x+a}, \qquad \beta = \&c. = 0;$$

and as

$$y = \frac{1}{\sqrt{1-x^2}} = \frac{1}{x+a} \text{ (vide } \textit{ante}\text{, p. 38.),*}$$

$$y\,dx = -\frac{da}{2x+a},$$

so that

$$A = -\frac{1}{2x+a}.$$

Let x_1 and x_2 be the two roots of our equation, we have thus to find the value of

$$A_1 + A_2 = -\left[\frac{1}{2x_1+a} + \frac{1}{2x_2+a}\right] = -\frac{2(x_1+x_2+a)}{(2x_1+a)(2x_2+a)} = 0,$$

since

$$x_1 + x_2 = -a.$$

Hence

$$y_1\,dx_1 + y_2\,dx_2 = 0,$$

and

$$\psi x_1 + \psi x_2 = c.$$

Since

$$x_1 + x_2 = -a,$$

and

$$x_1 x_2 = \frac{1}{2}(a^2 - 1),$$

we see that

$$x_1^2 + x_2^2 = 1, \qquad \text{or } x_2 = \sqrt{1-x_1^2}.$$

Hence, as $\psi x = \sin^{-1} x$, our result is merely this, that the sum of two arcs is constant if the sine of one is equal to the cosine of the other.

An infinity of analogous results may be obtained either by varying the form of y (*e. g.* by making $y = \sqrt{1-x^2}$), or by changing the equation (1.). A formula applicable to all forms of y, and which, for each, includes all the results which can be established with respect to it, is, it will readily be acknowledged, one of the most general in the whole range of analysis. Abel's principal result is a formula of this nature; he developed at considerable length the various consequences which may be deduced from it.

Generally speaking, the number of independent variables $a, b, \ldots c$ will be less than that of the different roots, $x_1, \ldots x_\rho$; hence a certain number, say m, of the roots may be looked on as independent (viz. as many as there are quantities $a, b, \ldots c$), and the rest will be functions of these. It may be shown that it will always be possible to make the *difference* $\mu - m$ constant, so that the sum of any number of the transcendents ψ is expressible by a fixed number of them, together with an algebraical and logarithmic function of the arguments, *i. e.* of $x_1, \ldots x_m$. In the case of elliptic integrals, it had long been known that the sum of two may be thus expressed by a third; and Legendre pointed out that the sum of any number may similarly be expressed by means of one. Accordingly it appears from the general theory, that in this case $\mu - m$ may be made equal to unity.

9. The history of this important theory is curious. It was developed by Abel in an essay which he presented to the Institute in the autumn of 1826, when he had scarcely completed his twenty-fourth year.

In a letter to M. Holmboe, appended to the edition of his collected works, Abel writes, "Je viens de finir un grand traité sur une certaine classe de fonctions transcendantes pour le présenter à l'Institut, ce qui aura lieu lundi

* The ambiguous sign of the radical is to our purpose immaterial.

prochain. J'ose dire sans ostentation que c'est un traité dont on sera satisfait. Je suis curieux d'entendre l'opinion de l'Institut la dessus. Je ne manquerai pas de t'en faire part." Long before this memoir was published Abel had become "chill to praise or blame." He died at Christiania in the spring of 1829.

M. Jacobi mentions in a note in Crelle's Journal, that while at Paris he represented, and as he believed not ineffectually, to Fourier, who was then one of the secretaries of the Institute, that the publication of this memoir would be very acceptable to mathematicians. A long period however was still to elapse before the publication took place. It was possibly retarded by the death of Fourier. In 1841 the memoir appeared in the seventh volume of the 'Mémoires des Savans Etrangers.' It was prepared for publication by M. Libri.

Thus for about fifteen years Abel's general theory remained unpublished; but in the meanwhile Crelle's Journal was established, and to the third volume of this he contributed a paper which contains a theorem much less general than the researches he had communicated to the Institute, but far more so than anything previously effected in the theory of the comparison of transcendents. This is commonly known as Abel's Theorem. Legendre, in a letter to Abel, speaks thus of the memoir in which it appeared:—"Mais le mémoire . . . ayant pour titre 'Remarques sur quelques propriétés générales,' &c., me parait surpasser tout ce que vous avez publié jusqu'à-présent par la profondeur de l'analyse qui y règne ainsi que par la beauté et la généralité des résultats." In a previous letter, with reference I believe to the same subject, he had remarked, "Quelle tête que celle d'un jeune Norvégien!"

Abel's theorem gives a formula for the comparison of all transcendental functions whatever whose differentials are irrational from involving the square root of a rational function of x.

In a very short paper in the fourth volume of Crelle's Journal, which must have been the last written of Abel's productions, the chief idea of his general theory is stated; and in the second volume of his collected works we find a somewhat fuller development of it, in a paper written before his visit to Paris, but not published during his lifetime.

While Abel's great memoir remained unpublished at Paris, several mathematicians, developing the ideas which he had made known in his contributions to Crelle's Journal, succeeded in establishing results of a greater or less degree of generality. Researches of this kind may be presented in a variety of forms, because the algebraical function to be integrated, which we have called y, may be defined or expressed in different ways. For instance, if M and N are general symbols denoting any integral functions of x, the two suppositions $y = \frac{\sqrt{M}}{N}$ and $y = \frac{M}{\sqrt{N}}$ are precisely equivalent, since by an obvious reduction, and by changing the signification of M and N, the one may be transformed into the other; and so in more general cases. Thus the same function may assume a variety of aspects, and there will be a corresponding variety in the form of our final results.

In Crelle's Journal we find a good many essays on this part of the subject: of these I shall now mention several.

M. Broch is the author of a paper in the twentieth volume of Crelle's Journal, p. 178. It relates to the integration of certain functions irrational in consequence of involving a polynomial of any degree raised to a fractional power. For these functions he establishes formulæ of summation, which of

course include Abel's theorem, since the latter relates to cases in which the fractional power in question is the $(\frac{1}{2})$th. Subsequently to the publication of this paper he presented to the Institute a memoir on the same subject, but gave to the functions to be integrated a different but not essentially more general form. This memoir, which was ordered to be printed among the 'Savans Etrangers,' but which will be found in Crelle's Journal (xxiii. 145), may be divided into two portions: the first contains results analogous to Abel's theorem; the second relates to the discussion and reduction of the transcendents which they involve. In this part of his researches M. Broch has followed the method, and occasionally almost adopted the phraseology of a memoir of Abel, on the reduction and classification of Elliptic Integrals (Abel's Works, ii. p. 93). MM. Liouville and Cauchy, in reporting on the memoir, conclude by remarking that the author "n'a pas trop présumé de ses forces en se proposant de marcher sur les traces d'Abel."

M. Jürgenson has contributed two papers to Crelle's Journal on the subject of which we are speaking. The first, which is very short, contains a general theorem for the summation of algebraical integrals* when the function to be integrated is expressed in a particular form. This paper appears in the nineteenth volume, p. 118. In the second (vol. xxiii. p. 126) the author reproduces the results he had already obtained, pointing out the equivalence of one of them to the theorem established in M. Broch's first essay. Besides this, he discusses a question connected with the reduction of algebraical integrals.

M. Ramus, in the twenty-fourth volume of Crelle's Journal, p. 69, has established two general formulæ of summation; from the second he deduces with great facility Abel's theorem, and also another result, which Abel mentions in a letter to Legendre, published in the sixth volume of Crelle's Journal, but which he left undemonstrated.

M. Rosenhain's researches (Crelle's Journal, xxviii. p. 249, and xxix. p. 1) embrace both the summation and reduction of algebraical integrals. His analysis depends on giving the function to be integrated a peculiar form, which he conceives leads to a simpler mode of investigation than any other.

A paper by Poisson will be found in the twelfth volume of Crelle's Journal, p. 89. It relates to the comparison of algebraical integrals, but is not I think so valuable as that great mathematician's writings generally are.

Beside the memoirs thus briefly noticed, I may mention two or three by M. Minding: that which appears in the twenty-third volume of Crelle's Journal, p. 255, is the one which is most completely developed.

There is also a very brief note by M. Jacobi in the eighth volume of Crelle's Journal.

10. To the Philosophical Transactions for 1836 and 1837 Mr. Fox Talbot contributed two essays, entitled 'Researches in the Integral Calculus.' These researches may be said to contain a development and generalisation of the methods of Fagnani. They are however far more systematic than the writings of the Italian mathematician, and if they had appeared in the last century would have placed Mr. Talbot among those by whom the boundaries of mathematical science have been enlarged. But it cannot be denied that they fall far short of what had been effected at the time they were published, nor does it appear that they contain anything of importance not known before. I have assuredly no wish to speak disparagingly of Mr. Talbot; his mathematical writings bear manifest traces of the ability he has shown in so many

* I have used the expression "algebraical integrals," though perhaps not correctly, to denote the integrals of algebraical functions.

branches of science*. But as in this country they seem to have been thought, and by men not apparently unqualified to judge, to contain great additions to our knowledge, I cannot avoid inquiring whether this be true.

Mr. Talbot points out in the early part of his first paper, that if there are $n-1$ symmetrical relations among the n variables $x, y \ldots z$, then the identical equation

$$\{y \ldots z\}\,dx + (x \ldots z)\,dy + \ldots + \{xy \ldots\}\,dz = d\{xy \ldots z\}$$

will assume the form

$$\varphi(x)\,dx + \varphi(y)\,dy + \ldots + \varphi(z)\,dz = d\{xy \ldots z\},$$

and thus give us

$$\int \varphi(x)\,dx + \int \varphi(y)\,dy + \ldots + \int \varphi(z)\,dz = xy \ldots z + C.$$

Precisely the same remark, though expressed in a different notation, is the foundation of M. Hill's memoir, published in 1834, on what he calls "functiones iteratæ." It will be found in Crelle's Journal, xi. p. 193. A much more general theorem might be established by similar considerations: they are of course applicable whether the function φ be algebraical or transcendent.

In the course of his researches, Mr. Talbot recognised the important principle, that the existence of $n-1$ symmetrical algebraical relations among n variables may be expressed by treating them as the roots of an equation, one of whose coefficients at least is variable, the others being either constant or functions of the variable one. Unfortunately he did not pass from hence to the more general view, that the existence of $n-p$ symmetrical relations may be expressed in a similar manner if we consider p of the coefficients of the equation as arbitrary quantities. Had he done so, it is possible, though not likely, that he would have rediscovered Abel's theorem; but as it is, he has never introduced, except once, and then as it were by accident, more than one arbitrary quantity. Thus only one of his variables is independent, and consequently, in more than one instance, his results are unnecessarily restricted cases of more general theorems.

The character of his analysis will be perceived from what has been said. If $\int X\,dx$ be the transcendent to be considered, X being an algebraical function of x, he makes the following assumption—

$$X = f(xv),$$

v being a new variable, and f a rational function. From this assumption he deduces an algebraical equation in x, the coefficients of which are rational functions of v. This equation then is one of those of which we have spoken, by means of which the function to be integrated can be expressed in a rational form. Taking the sum with respect to the roots of this equation, we get

$$\Sigma(X\,dx) = \Sigma(f(xv)\,dx).$$

It must be remarked that many forms might be assigned to the function f, which would give rise to a difficulty, of the means of surmounting which Mr. Talbot has given no idea. If x and v are mixed up in $f(xv)$, it is manifest that we cannot integrate $f(xv)\,dx$, since v is a function of x, which

* It must be remembered also that Mr. Talbot admits himself to have been anticipated to a considerable extent by the publication of Abel's theorem.

if we eliminate we merely return to our function X. We must therefore express $\Sigma f(xv)\,dx$ in the form $V\,dv$, V being a function and, as Abel has shown, an integrable function of v. Abel has given formulæ by means of which this reduction may be effected in all possible cases. But there is nothing analogous to this in the writings of Mr. Talbot, and consequently he could not, setting aside the defect already noticed, obtain results as general as many previously known. In Mr. Talbot's investigations, $f(xv)\,dx$ is such that $\Sigma f(xv)\,dx$ may be put in the form—

$$V_1 \Sigma \{\varphi'_1 x\,dx\} + V_2 \Sigma \{\varphi'_2 x\,dx\} + \&c.,$$

$\varphi_1 x$, $\varphi_2 x$, &c. (of which $\varphi'_1 x$, $\varphi'_2 x$, &c. are the derived functions) being rational functions of x. Then $\Sigma \varphi x =$ a rational function of v by a well-known theorem. Let the form of this function be ascertained, and let us denote it by χv. Then differentiating,

$$\Sigma \varphi' x\,dx = \chi' v\,dv,$$

and hence

$$\Sigma X dx = \Sigma f(xv)\,dx = [V_1 \chi'_1 v + V_2 \chi'_2 v + \ldots]\,dv,$$

and the second side of this equation is of course rational and integrable. But the form of the function $f(xv)$ is unnecessarily restricted in order that this kind of reduction may be possible. Nevertheless, Mr. Talbot's papers, from their fulness of illustration and the clear manner in which particular cases of the general theory are worked out by independent methods, will be found very useful in facilitating our conceptions of the branch of analysis which forms as it were the link between the theory of equations and the integral calculus.

In Mr. Talbot's second memoir (Phil. Trans. 1887, part 2. p. 1) he has applied his method to certain geometrical theorems. Three of them relate to the ellipse, and are proved by the three following assumptions:—

$$\left\{\frac{1-e^2x^2}{1-x^2}\right\}^{\frac{1}{2}} = 1 + vx, \text{ or } = \frac{1-ex}{\sqrt{v}}, \text{ or } = \frac{\sqrt{v}}{1-x}.$$

These assumptions are all cases of the following—

$$\left\{\frac{1-e^2x^2}{1-x^2}\right\}^{\frac{1}{2}} = \frac{c+c'x}{a+a'x},$$

where a, a', c, c' are arbitrary quantities. The results of this assumption are completely worked out by Legendre (Théorie des Fonctions Elliptiques, iii. p. 192) in showing how the known formulæ of elliptic functions may be derived from Abel's theorem. Mr. Talbot's first theorem is a case of the fundamental formula for the comparison of elliptic arcs. This remark has reference to an inquiry which Mr. Talbot suggests as to the relation in which his theorems stand to the results obtained by Legendre and others.

In conclusion, it may be well to observe that Mr. Talbot has remarked that, apparently, a solution discovered by Fagnani of a certain differential equation cannot be deduced from Abel's theorem; but as this solution may be easily derived from the ordinary formula for the addition of elliptic integrals of the first kind it is manifestly included in the theorem in question.

II.

11. I now come to the history of researches into the properties of particular classes of algebraical transcendents. The earliest, and still perhaps the most important class of these researches relates to the transcendents

which are commonly called elliptic functions or elliptic integrals. For a reason which will be mentioned hereafter the latter name seems preferable, and it is sanctioned by the authority of M. Jacobi, though the former was used by Legendre. Elliptic integrals then may be defined as those whose differentials are irrational in consequence of involving a radical of the form $\sqrt{\{\alpha+\beta x+\gamma x^2+\delta x^3+\varepsilon x^4\}}$. But it may perhaps be more correct to say that all such integrals may be reduced to three standard integrals, to which the name of elliptic integrals has been given.

In the Turin Memoirs for 1784 and 1785, p. 218, Lagrange considered, as has been already mentioned, the theory of these transcendents. He showed that the integration of every function irrational in consequence of containing a square root may be made to depend on that of a function of the form $\frac{P}{R}$, P being rational, and R the radical in question; and that if under the sign of the square root x does not rise above the fourth degree, it may ultimately be made to depend on that of $\frac{N\,dx}{\sqrt{(1\pm p^2x^2)(1\pm q^2x^2)}}$, where N is rational in x^2. He thus laid the foundation of that part of the theory of elliptic transcendents in which a proposed integral is reduced to certain canonical or standard forms, or to the simplest combination of such forms of which the case admits. In Legendre's earliest writings on elliptic functions there is nothing relating to this part of the subject. Having thus, in the simple manner which distinguishes his analysis, reduced the general case to that which admits of the application of his method, Lagrange proceeded to prove that if we introduce a new variable whose ratio to x is the subduplicate of the ratio of $1\pm p^2x^2$ to $1\pm q^2x^2$, the last written integral is made to depend on another of similar form, but in which p and q are replaced by new quantities p^1 and q^1. If p is greater than q, p^1 will be greater than p, and q^1 less than q, and thus by successive similar transformations we ultimately come to an integral in which q is so small that the factor $1\pm q^1x^2$ may be replaced by unity, and the elliptic integral is therefore reduced to a circular or logarithmic form. Or by successive transformations in the opposite direction we come to an integral in which p^1 and q^1 are sensibly equal, in which case also the elliptic integral is reduced to a lower transcendent. This most ingenious method is the foundation of all that has since been effected in the transformation of elliptic integrals, or at least whatever has been done has been suggested by it. Thus it is to Lagrange that we owe the origin of two great divisions of the theory of these functions.

In the Memoirs of the French Academy for 1786, p. 616, we find Legendre's first essay on the subject to which he afterwards gave so much attention. We recognise in it what may I think be considered the principal aim of his researches in elliptic functions, namely to facilitate, by the tabulation of these functions, the numerical solution of mathematical and physical problems.

He begins, not with a general form as Lagrange had done, but with the integral $\int\sqrt{1-c^2\sin^2\varphi}\,d\varphi$, which as we know represents an elliptic arc, and shows how other functions, for instance the value of the hyperbolic arc, may be expressed by means of it, and of its differential coefficient with respect to the eccentricity c. The memoir does not contain much that is now of interest. After writing it he became aware of the existence of Landen's researches; and in a second memoir appended to the first gave a demonstration of Landen's principal theorem. This demonstration is founded on

Legendre's own methods, and he deduces from it the remarkable conclusion, that if of a series of ellipses, whose eccentricities are connected by a certain law, we could rectify any two, we could deduce from hence the rectification of all the rest. The law connecting the eccentricities of the ellipses is that which would be obtained by making use of Lagrange's method of transformation, with which accordingly this result is closely allied.

Legendre's next work was an essay on transcendents *, presented to the Academy in 1792 and published separately the year after. It contains the same general view as that which is developed in the first volume of the 'Exercices de Calcul Intégral,' which appeared in 1811.

12. The theory of elliptic functions, as it is presented to us by Legendre, may conveniently be considered under the following heads :—

a. The reduction of the general integral,

$$\int \frac{P\,dx}{\sqrt{\alpha+\beta x+\gamma x^2+\delta x^3+\varepsilon x^4}},$$

in which P is rational to three standard forms, since known as elliptic integrals of the first, second and third kinds †.

This classification, though the reduction of the general integral had, as we have seen, been already considered by Lagrange, is I believe entirely due to Legendre. If we consider how much it has facilitated all subsequent researches, we can hardly over-rate the importance of the step thus made. It may almost be said that Legendre, in thus showing us the primary forms with which the theory of elliptic integrals is conversant, created a new province of analysis : he certainly gave unity and a definite form to the whole subject.

For the three species of functions thus recognised Legendre suggested the names of *nome*, *epinome* and *paranome*, the name of the first being derived from the idea that it involves, so to speak, the law on which the comparison of elliptic integrals depends. But these names do not seem felicitous, nor have they I believe been adopted. To this part of the subject an important theorem relating to the reduction of elliptic integrals of the third kind, whose parameters are imaginary, seems naturally to belong.

β. The comparison of elliptic integrals of the same form differing only in the value of the variable, or as it is often called, the amplitude of each. This part of the subject divides itself into three heads, corresponding to the three classes of integrals. The fundamental results are to be found in the memoirs of Euler, of which we have already spoken. By Legendre however they were more fully developed.

It is interesting to observe that Legendre suggested that the discovery of

* A translation of it appeared in Leybourne's Mathematical Repository, vols. ii. and iii. The original I have not seen—it has long been scarce.

† These three forms are

$$\int_0^x \frac{dx}{\sqrt{(1-x^2)(1-c^2x^2)}}\,;\quad \int_0^x \sqrt{\frac{1-c^2x^2}{1-x^2}}\,dx\,;\quad \int_0^x \frac{dx}{(1+nx^2)\sqrt{(1-x^2)(1-c^2x^2)}}\,.$$

Legendre always replaces x by $\sin\varphi$, so that the integrals become

$$\int_0^\varphi \frac{d\varphi}{\sqrt{1-c^2\sin^2\varphi}}\,;\quad \int_0^\varphi \sqrt{1-c^2\sin^2\varphi}\,d\varphi\,;\quad \int_0^\varphi \frac{d\varphi}{(1+n\sin^2\varphi)\sqrt{1-c^2\sin^2\varphi}}\,.$$

The radical $\sqrt{1-c^2\sin^2\varphi}$ is often denoted by Δ.

The constant c is called the *modulus*; the second constant n (in the third kind) is called the *parameter*. The modulus may always be supposed less than unity, and if $c=\sin\epsilon$, then ϵ is the *angle of the modulus*.

Euler (namely that the differential equation $\frac{dx}{\sqrt{f(x)}}+\frac{dy}{\sqrt{f(y)}}=0$ admits of an algebraical integral, $f(x)$ being the polynomial $\alpha+\beta x+\gamma x^2+\delta x^3+\varepsilon x^4$) might be generalised, if we consider the differential equation $\frac{dx}{\sqrt{f(x)}}+\frac{dy}{\sqrt{f(y)}}+\ldots+\frac{dz}{\sqrt{f(z)}}=0$. He remarks that this is perhaps the only way in which it can be generalised.

γ. Theorems relating to the comparison of different kinds of elliptic functions. One of the most remarkable of these is the relation between the complete integrals (those, namely, in which the variable x is unity) of the first and second kind, the moduli of which are complementary; that is, the sum of the squares of whose moduli is equal to unity. Legendre's demonstration of it is rather indirect, but many others have been since given. Another theorem may be mentioned,—that the complete integral of the third kind can always be expressed by means of the complete integrals of the first and second. A third and most important result shows that in elliptic integrals of the third kind we may distinguish two separate species, and that to one or other of these any such integral may be reduced. A memorable discovery of M. Jacobi has greatly increased the importance of this subdivision, of which we shall hereafter speak more fully. This part of the subject is, I imagine, entirely due to Legendre.

δ. The evaluation of elliptic integrals by means of expansions.

ε. The method of successive transformations. The idea of this method originated, as we have seen, with Lagrange. It is developed at great length by Legendre, with a special reference to the modifications required in applying it to the different species of integrals. As Lagrange had shown, the series of transformed integrals extending indefinitely both ways conducts us, in whichever direction we follow it, towards a transcendent of a lower kind than an elliptic integral, or in other words, towards a logarithmic or circular integral. There are thus two modes of approximation, one of which depends on a series of integrals with increasing moduli, and the other on a series whose moduli decrease. Thus for the three species of integrals there will be in all six approximative processes to be considered. In the case of the elliptic integral of the third kind, we have to determine the law of formation of the successive parameters n, n', &c.

ζ. Reductions of transcendents not contained in the general formula $\left(e.g.\int\frac{dx}{\sqrt{1-x^6}}\right)$ to elliptic integrals.

η. Lastly, applications to various mechanical and geometrical problems.

This analysis, however slight, will give an idea of the contents of that part of the 'Exercices de Calcul Intégral' which relates to elliptic functions. In the third volume there are tables for facilitating the calculation of integrals of the first and second kind: they are accompanied with an explanation of the manner in which they were constructed. The ninth table is one with double entry, the two arguments being the angle of the modulus and the amplitude.

13. In 1825 Legendre presented to the Académie des Sciences the first volume of his 'Traité des Fonctions Elliptiques.' A great part of this work is precisely the same as the 'Exercices de Calcul Intégral.' By far the most important addition to the theory of elliptic functions consists in the discovery of a new system of successive transformations quite distinct from that of Lagrange.

In the earlier work Legendre had shown that a certain transcendent might be expressed in two ways by means of elliptic integrals of the first kind. Comparing the two results, he obtained a very simple relation between the two elliptic integrals. Their moduli are complementary; while the ratio of the Δ's in the two integrals can be expressed rationally in terms of the sine of the amplitude of one. This circumstance seems to have suggested to Legendre the possibility of generalising the result. He accordingly assumed a relation between the amplitudes of two integrals, of which the equation subsisting in the theorem of which we have been speaking is a particular case; and showed from hence that a simple relation perfectly similar to that which he had obtained in the particular instance existed between the two integrals, viz. that they bore to each other a ratio independent of their amplitudes. Their moduli are connected by an algebraical equation, but are not complementary. This circumstance therefore now appeared to be unessential, though in the 'Exercices' the investigation is introduced for the sake of exhibiting a case in which an integral may be transformed into another with a complementary modulus.

Legendre thus obtained a new kind of transformation, which might be repeated any number of times or combined in an infinite variety of ways with that of Lagrange. To illustrate this he constructed a kind of table—a "damier analytique." In the central cell is placed the original modulus c. All the moduli contained in the same horizontal row are derivable from one another by Lagrange's scale of moduli; those in each vertical row by the newly-discovered scale. He seems to have been very much struck by the infinite variety of transformations of which elliptic integrals admit. The integral of the first kind is especially remarkable, because of the simplicity of the relation which connects it with any of its transformations, viz. that their ratio is independent of the amplitudes.

Legendre's second work was, as we have remarked, presented to the Academy in 1825, but it was not published till 1827. In the summer of 1827 M. Jacobi announced in Schumacher's 'Astronomischen Nachrichten,' No. 123, that he was in possession of a general method of transformation for elliptic integrals of the first kind. He was not acquainted with Legendre's discovery of a new scale, and as an illustration of the general theorem gave two cases of it, the first being equivalent to Legendre's method of transformation. Thus much was announced in a letter to M. Schumacher, dated June 13th; but in one of a later date (August 2nd) he gave a formal enunciation of his theorem, but without demonstration. The two communications appear consecutively (Ast. Nach. vi. p. 33).

In No. 127 of the Nachrichten, vi. p. 133, M. Jacobi gave a demonstration of his theorem.

If we can so determine y in the terms of x as to satisfy the differential equation

$$\frac{dy}{\sqrt{(1-y^2)(1-\lambda^2 y^2)}} = \frac{1}{M}\,\frac{dx}{\sqrt{(1-x^2)(1-k^2x^2)}}\ (\text{M being constant}),$$

it is manifest that we shall have (F denoting the elliptic integral of the first kind) $F(kx) = M\,F(\lambda y)$, provided that y and x vanish together. The question therefore is, how may the differential equation be satisfied, for it is clear that by means of a solution of it we *transform* the elliptic integral $F(kx)$ into another, viz. into $F(\lambda y)$.

M. Jacobi shows that if y be equal to $\frac{U}{V}$, U and V being integral func-

tions of x, the differential equation will be satisfied, provided U and V fulfil two general conditions, the second of which is found to be deducible from the first. He then makes an assumption which is equivalent to assigning particular forms to U and V, and thence shows, by a most ingenious method, that these forms of U and V are such as to fulfil the first of the required conditions, which, as has been said, implies the other. He thus verifies, *à posteriori*, the assumed value of the function y.

In proving that the forms assigned for U and V have the required property, it is necessary to pass from an expression of the value of $1-y$ in terms of x to one of $1-\lambda y$ in terms of the same quantity. This is done by means of a remarkable property of the functions U and V, namely, that if in both x be replaced by $\frac{1}{kx}, \frac{U}{V}$ or y will (the constants being properly adjusted) become $\frac{V}{\lambda U}$ or $\frac{1}{\lambda y}$. Therefore, in any form in which the relation connecting y and x can be put, we may replace x by $\frac{1}{kx}$, provided we at the same time replace y by $\frac{1}{\lambda y}$. This has been called the principle of double substitution, and by means of it we pass from the expression of $1-y$ to that of $1-\frac{1}{\lambda y}$, and thence obtain that of $1-\lambda y$. It is to be observed that this principle is used merely to prove a certain property of the functions U and V. Of course, as the change of x into $\frac{1}{kx}$ implies that of y into $\frac{1}{\lambda y}$ in the finite relation between these quantities, the same thing will be true in the differential equation by which they are connected, a remark which may very easily be verified. But, on the other hand, it by no means follows that because it is true in the differential equation therefore any assumed finite relation between y and x having this property is the integral required. The property in question therefore does not enable us to *verify* any assumed value of y.

This remark has reference to a communication from Legendre which appears in No. 130 of Schumacher's Nachrichten, vi. p. 201. In it he gives an account of M. Jacobi's researches, and an outline of the demonstration of which we have been speaking. I find it impossible to avoid the conclusion that this great mathematician mistook the character of the demonstration in question, and that to him it appeared to be in effect a mere verification of the assumed value of y by means of the principle of double substitution. He remarks that the direct substitution of the value of y in the differential equation is impracticable, but that M. Jacobi had avoided this substitution by means of "une propriété particulière de cette équation qui doit être commune aux intégrales qui la représentent." This property is the principle of double substitution; and after showing that it is true of the differential equation, the writer proceeds thus: "Ce principe une fois posé, rien n'est plus facile que de vérifier l'équation trouvée $y=\frac{U}{V}$, car par la double substitution on obtient la même valeur de y à un coefficient près qui doit être égal à l'unité;" and, after a remark to our present purpose immaterial, concludes, "Ainsi se trouve démontrée généralement l'équation $y=\frac{U}{V}$ ainsi que, etc."

As we have seen, such a verification would be wholly inconclusive, nor is

the essential point of M. Jacobi's reasoning, namely, that the assumed forms of U and V satisfy the general condition, laid down at the outset of his demonstration, here adverted to.

In 1828 Legendre published the first supplement to the 'Traité des Fonctions Elliptiques,' &c. It contains an account of the researches of M. Jacobi, and of a memoir by Abel inserted in the third volume of Crelle's Journal. The account here given of M. Jacobi's demonstration is fuller and more explicit than that already noticed. It leaves, I think, no doubt of the error into which Legendre had fallen. No notice whatever is taken of the first part of M. Jacobi's reasoning: and after remarking that the differential equation is satisfied when the double substitution is made, he goes on, "Tout se reduit donc à faire cette double substitution dans l'intégrale $y = \frac{x}{\mu}\frac{U}{V}$ et à examiner si elle est satisfaite." After showing that it is so, he adds, "Par ce procédé très simple il est constaté que l'équation $y = \frac{x}{\mu}\frac{U}{V}$ satisfait..... à l'équation différentielle dont l'intégrale est $F(k\varphi) = \mu F(k\psi)$, etc." (Trait. des Fonct. Ell., iii. p. 10).

Legendre remarks, that although M. Jacobi's demonstration rests on "un principe incontestable et très ingénieux," it is still desirable to have another verification of so important a theorem. He accordingly gives an original demonstration of it, which is however more nearly allied to M. Jacobi's than to him it seemed to be. This demonstration had already been hinted at in his communication to the Nachrichten. The principal difference is, that while M. Jacobi proved generally that if the first of the two required conditions were satisfied, the second would also be so, and then showed that the forms assigned to U and V satisfied the first condition; Legendre shows the assigned forms are such as to satisfy both conditions, on the connection between which it is therefore unnecessary for him to dwell. In the third supplement to the 'Traité des Fonctions Elliptiques,' Legendre has given another demonstration of M. Jacobi's theorem, remarking that it is both more rigorous and more like M. Jacobi's than that which he had first given. I have thought it necessary to make these remarks, because it has been said that it was in the supplements to Legendre's work that the demonstration of this theorem received "le dernier degré de rigueur"*.

14. In 1829 M. Jacobi's great work on elliptic functions, the 'Fundamenta Nova Theoriæ Functionum Ellipticarum,' was published at Kœnigsberg. It contains his researches not merely on the theory of transformation, but also with respect to other parts of the subject. But the great problem of transformation is the fundamental idea of the whole work; the other parts are subordinate to it, or at least derived from it. The subject is treated with great fulness of illustration and in a manner not unlike that of Euler.

M. Jacobi begins by considering the possibility of transforming the general transcendent whose differential coefficient is unity divided by the square root of a polynomial of the fourth degree. Subsequently, having shown that this transcendent may be transformed by introducing a new variable y equal to the quotient of two integral functions of x, and also that the general transcendent may be reduced to one of the form $\int \frac{dy}{\sqrt{(1-y^2)(1-\lambda^2 y^2)}}$, he proceeds to consider the latter in detail.

The first step of this reasoning, viz. the possibility of the transformation, depends on a comparison of the number of the disposable quantities in the

* Verhulst, Traité Elémentaire des Fonctions Elliptiques.

assumed value of y with that of the conditions required, in order that the quantity under the radical in the transformed expression may be equal to the square of an integral function of x multiplied by four unequal linear factors. It is shown that the number of disposable quantities exceeds by three that of the required conditions. But, as Poisson has remarked in the report already mentioned (Mem. de l'Institut. x. p. 87), and as M. Jacobi himself intimates, this does not amount to an absolute *à priori* proof of the possibility of the transformation; *non constat* but that some of these conditions may be incompatible.

Granting however the possibility of putting the quantity under the radical in the required form, it is shown, as in Schumacher's Journal, that this condition is not only necessary but also sufficient, or, in other words, that it involves the second condition already mentioned.

The transcendent $\int \frac{dy}{\sqrt{(1-y^2)(1-\lambda^2 y^2)}}$ may be transformed by assuming $y = \frac{U}{V}$, U being composed wholly of odd powers of x, and V of even powers of it. If the degree of U be greater than that of V, the transformation is said to be of an odd order, and of an even order in the contrary case.

This being premised, M. Jacobi discusses the particular cases of the transformations of the third and of the fifth order. The first is the same as that of Legendre. It is shown that if we put

$$y = \frac{(v + 2u^3)vx + u^6x^3}{v^2 + v^3u^2(v + 2u^3)x^2},$$

where u and v are constants connected by the following equation—

$$u^4 - v^4 + 2uv\{1 - u^2v^2\} = 0,$$

we shall get

$$\frac{dy}{\sqrt{(1-y^2)(1-\lambda^2y^2)}} = \frac{v + 2u^3}{v} \cdot \frac{dx}{\sqrt{(1-x^2)(1-k^2x^2)}},$$

in which $k = u^4$ and $\lambda = v^4$. The equation connecting u and v is called the modular equation.

The "principle of double substitution" may be illustrated by writing $\frac{1}{u^4x}$ for x in the expression for y, which then becomes, according to the principle in question, $\frac{1}{v^4y}$.

If we seek to show that the assigned value of y actually satisfies the differential equation just stated, we begin by finding the value of $1 - y$. Reducing this value by means of the equation between u and v, we can put it in the form $(1-x)\frac{R^2}{V}$, R being an integral function of x and V, as heretofore the denominator of the expression for y. The value of $1 + y$ is hence got by changing the sign of x, while that of $1 - v^4y$ is obtained by simultaneously replacing x and y respectively by $\frac{1}{u^4x}$ and $\frac{1}{v^4y}$ and reducing. Similarly for $1 + v^4y$. Hence it will appear that

$$(1-y^2)(1-v^8y^2) = (1-x^2)(1-u^8x^2)\frac{S^2}{V^2} \quad . \quad . \quad . \quad (\alpha.)$$

where S, like R, is integral. By differentiating and reducing, we then show that

$$dy = \frac{v + 2u^3}{v} \frac{S}{V^2} dx,$$

and combining these two results obtain the required verification.

The essence of M. Jacobi's demonstration consists in showing that if the value of y in terms of x is such that an equation of the form $(\alpha.)$ subsists, then necessarily

$$\frac{dy}{dx} = \mu \frac{S}{V^2}, \quad \ldots\ldots\ldots (\beta.)$$

where μ is a constant; the existence of the two equations $(\alpha.)$ and $(\beta.)$ being equivalent to the two conditions of which we have already spoken (p. 48). In the particular case we are now considering,

$$\mu = \frac{v + 2u^3}{v}.$$

15. After considering the transformation of the fifth order (in which the modular equation is

$$u^6 - v^6 + 5u^2v^2\{u^2 - v^2\} + 4uv\{1 - u^2v^2\} = 0),$$

M. Jacobi prepares the way for a more general investigation by introducing a new notation. This step is one of the highest importance. We have been in the habit of calling ϕ the *amplitude* of the integral $\int_0^{\phi} \frac{d\phi}{\sqrt{1 - k^2 \sin^2 \phi}}$: let this integral be called u. The new notation is contained in the equation $\phi = \text{am } u$; or if we call $\sin \phi, x$, so that $u = \int_0^x \frac{dx}{\sqrt{(1 - x^2)(1 - k^2 x^2)}}$, then $x = \sin \text{am } u$.

A new notation is in itself merely a matter of convenience: what gives it importance is its symbolizing a new mode of considering any subject. We had hitherto been accustomed to look on the value of the elliptic integral as a function of its amplitude, to make the amplitude (if the expression may so be used) the independent variable. But in reality a contrary course is on many accounts to be preferred. We have in the more advanced part of the theory more frequently occasion to consider the value of the amplitude as determined by the corresponding value of the integral than *vice versâ*; and it therefore becomes expedient to frame a notation by which the amplitude may be expressed as a function of the integral. In a paper in the ninth volume of Crelle's Journal by M. Jacobi, which, like many of his writings, contains in a short compass a philosophical view of a wide subject, he has made use of the analogy between circular and elliptic functions to illustrate the importance of the new notation for the latter. When the modulus of an elliptic integral of the first kind is equal to zero, the integral becomes $\int_0^x \frac{dx}{\sqrt{1 - x^2}}$, which, as we know, is equal to the arc whose sine is x, or to $\sin^{-1} x$. Now this is a function which we have much less often occasion to express than its inverse $\sin x$, and we accordingly always look on the latter as a *direct*, and on the former as an *inverse* function. Yet in the case of elliptic functions, the functional dependence for which we had an explicit and recognised notation, viz. that of the integral on the amplitude, corresponds to that which in circular functions has always and almost necessarily been treated merely as an inverse function. The origin of this discrepancy is obvious; our knowledge of the nature of circular functions is not derived

from the algebraical integrals connected with them, and therefore these integrals are not brought so much into view as in the theory of elliptic functions the corresponding integrals necessarily are; but it is certain that while the discrepancy continued to exist the subject could never be fully or satisfactorily developed. The maxim "verba vestigia mentis" is as true of mathematical symbols as of the elements of ordinary language.

We shall see hereafter that Abel took the same step in his first essay on elliptic functions. At present I shall only remark, that one of the earliest consequences of the new notation was the recognition of a most important principle, viz. that the "inverse function" $\sin \operatorname{am} u$, that is, the function corresponding to $\sin u$ in circular functions, is doubly periodic, or that it retains the same value when u increases by any multiple either of a certain real or of a certain imaginary quantity. Now M. Jacobi has shown that no function* can be triply periodic, and therefore these inverse functions possess the most general kind possible of periodicity, a property which gives them great analytical importance.

Following M. Jacobi, we shall henceforth give the name of elliptic functions to those which are analogous to circular functions. It is on this account better to call Legendre's functions elliptic integrals than, as he has done, elliptic functions (vide *ante*, p. 44).

By the new notation we are led to consider a great variety of formulæ analogous to those of ordinary trigonometry. The sine or cosine of the amplitude of the sum of two quantities may be expressed in terms of the sines and cosines of the amplitudes of each, &c.†; and we have only to make the modulus equal to zero to pass from what has sometimes, though not with much propriety, been called elliptic trigonometry to the common properties of circular functions.

M. Jacobi gives a table of formulæ relating to the new elliptic functions, and proceeds to apply their properties to the problem of transformation. It was in this manner that he had treated the problem in the Nachrichten. As

* *i. e.* no function of one variable.

† The fundamental formulæ are—

$$\sin \operatorname{am}(u+v) = \frac{\sin \operatorname{am} u \cos \operatorname{am} v \,\Delta \operatorname{am} v + \sin \operatorname{am} v \cos \operatorname{am} u \,\Delta \operatorname{am} u}{1 - k^2 \sin^2 \operatorname{am} u \sin^2 \operatorname{am} v};$$

$$\cos \operatorname{am}(u+v) = \frac{\cos \operatorname{am} u \cos \operatorname{am} v - \sin \operatorname{am} u \sin \operatorname{am} v \,\Delta \operatorname{am} u \,\Delta \operatorname{am} v}{1 - k^2 \sin^2 \operatorname{am} u \sin^2 \operatorname{am} v};$$

$$\Delta \operatorname{am}(u+v) = \frac{\Delta \operatorname{am} u \,\Delta \operatorname{am} v - k^2 \sin \operatorname{am} u \sin \operatorname{am} v \cos \operatorname{am} u \cos \operatorname{am} v}{1 - k^2 \sin^2 \operatorname{am} u \sin^2 \operatorname{am} v};$$

k being the modulus, and $\Delta \operatorname{am} u = \sqrt{1 - k^2 \sin^2 \operatorname{am} u}$. If

$$K = \int_0^{\frac{\pi}{2}} \frac{d\phi}{\sqrt{1 - k^2 \sin^2 \phi}} \text{ and } K' = \int_0^{\frac{\pi}{2}} \frac{d\phi}{\sqrt{1 - k'^2 \sin^2 \phi}},$$

where $k^2 + k'^2 = 1$, then it may be shown that

$$\sin \operatorname{am}(u + 4K) = \sin \operatorname{am} u,$$

and

$$\sin \operatorname{am}(u + 2K'\sqrt{-1}) = \sin \operatorname{am} u,$$

so that $4K$ is the *real* and $2K'\sqrt{-1}$ the *imaginary* period of $\sin \operatorname{am} u$. Hence it is obvious that we shall have generally

$$\sin \operatorname{am}(u + 4mK + 2nK'\sqrt{-1}) = \sin \operatorname{am} u,$$

m and n being any integers.

in his earlier essay, he assumes y equal to a rational function of x, whose coefficients are elliptic functions, and shows that this assumption satisfies the differential equation already mentioned. It may be asked what is gained by the introduction of elliptic functions into a problem of which, as we have seen, particular cases (*e.g.* the transformations of the third and fifth order) can be solved by algebraical considerations. The answer is, that the properties of these functions enable us to transform the assumed relation between y and x in a manner which would otherwise be impracticable. It is conceivable that any particular case might be solved by mere algebra, but it does not seem possible to discover in this way a general theorem for transformations of all orders, and practically the labour of obtaining the formulæ for the transformation of any high order would be intolerable.

Having proved the theorem for transformation in nearly the same manner as he had already done, M. Jacobi developes the demonstration which, as we have said, Legendre hinted at in No. 130 of Schumacher's Journal.

He then proceeds to consider the various transformations of any given order. We have seen that the modular equation for those of the third order rises to the fourth degree, that is to say, for a given value of the modulus of the original integral four new moduli exist, corresponding to four new integrals, into which the given one may be transformed. These four transformations are all included in the general formula for the third order; but it is to be remarked that in general only two of the roots of the modular equation are real. Thus there are two real transformations and no more. The same thing is true, *mutatis mutandis*, of the transformations of any prime order (to which M. Jacobi's attention is chiefly directed), that is to say, there will be $n+1$ transformations of the nth order, $n-1$ of which are imaginary. The two real transformations are called the first and the second; the second is sometimes called the impossible transformation, because it presents itself in an imaginary form*. Of the formulæ connected with these two transformations M. Jacobi gives copious tables.

He next shows, in a very remarkable manner, that, corresponding to a transformation in which we pass from a modulus k to a modulus λ, there exists another, whose formulæ are derivable from those of the former, in which we pass from a modulus $\sqrt{1-k^2}$ to a modulus $\sqrt{1-\lambda^2}$, or which connects moduli *complementary* to λ and k. The latter is accordingly called, with reference to the former, the *complementary* transformation. The first real transformation of k corresponds to the second real transformation $\sqrt{1-k^2}$, and *vice versâ*.

The next theorem which M. Jacobi demonstrates is not less remarkable. It is that the combination of the first and second real transformations gives a formula for the multiplication of the original integral, or, in other words, that the modulus of the integral which results from this double transformation is the same as that of the original integral, so that the two integrals differ only in their amplitudes. Of this theorem he had in the earlier part of the work proved some particular cases†.

* Mr. Bronwin, in the Cambridge Mathematical Journal and in the Phil. Mag., has made some objections to this transformation; but from a correspondence which I have recently had with him, I believe I am justified in stating that he does not object either to M. Jacobi's result or to the logical correctness of his reasoning, but only to the form in which the result is exhibited.

† It may be shown that if we pass from k to λ by the first transformation, we can pass from $\sqrt{1-\lambda^2}$ to $\sqrt{1-k^2}$ also by the first transformation. Also, as has been said, we derive from the transformation $\{k \text{ to } \lambda\}$ a transformation $\{\sqrt{1-k^2} \text{ to } \sqrt{1-\lambda^2}\}$, and

After fully developing this part of the subject, he next treats of the nature of the modular equation, and shows that it possesses several remarkable properties. One is, that all modular equations, of whatever order, are particular integrals of a differential equation of the third order, of which the general integral can be expressed by means of elliptic transcendents.

16. We now enter on the second great division of M. Jacobi's researches, the evolution of elliptic functions.

The evolution of elliptic functions into continued products with an infinite number of factors presents itself as the limit towards which M. Jacobi's theorem for the transformation of the nth order tends as n increases *sine limite*. It is for this reason that we may look on the problem of transformation as the leading idea in M. Jacobi's researches.

We may in some degree illustrate these evolutions by a reference to circular functions. A sine is, as we know, an elliptic function whose modulus is zero. Now if k is zero, λ is also zero. Thus if we apply a formula of transformation to a sine, we shall be led to another sine either of the same or of a multiple arc. Accordingly the first real transformation degenerates in the case in question into the known formula for the sine of a multiple arc; while the second, leading us merely to the sine of the same arc, becomes illusory. Thus in the case of a sine, transformation is merely multiplication; but from the formula for multiplication, viz.

$$\sin(2m+1)\theta=(2m+1)\sin\theta\left(1-\frac{\sin^2\theta}{\sin^2\frac{\pi}{2m+1}}\right)\cdots\left(1-\frac{\sin^2\theta}{\sin^2\frac{2m\pi}{2m+1}}\right)$$

we at once deduce, by making $(2m+1)\theta=\varphi$ and $2m+1$ infinite, the common formula

$$\sin\varphi=\varphi\left(1-\frac{\varphi^2}{\pi^2}\right)\left(1-\frac{\varphi^2}{4\pi^2}\right)\cdots\cdots$$

This then is a formula of evolution deduced from the first real transformation. It is however only when k is zero that the first transformation will give such a formula. In all other cases it is, for a reason which we cannot here enter on, impossible to derive from it a formula of this kind. M. Jacobi's formulæ are accordingly derived from the second real transformation, and therefore are illusory when k is zero, or for the case of the sine. There is nothing therefore strictly analogous to them in the theory of angular sections. By means of them we express the function sin am x in terms of sin mx, m being a certain constant.

From the fundamental expressions in continued products, of which there are three, many important theorems may be derived. This part of the subject seems to admit of almost infinite increase, and it is difficult to give any general view of it. I may, however, mention a remarkable transcendental

similarly from $\{\sqrt{1-\lambda^2}$ to $\sqrt{1-k^2}\}$ a transformation $\{\lambda$ to $k\}$. The first and last of these transformations correspond respectively to the differential equations—

$$\frac{dy}{\sqrt{(1-y^2)(1-\lambda^2y^2)}}=\frac{1}{M}\frac{dx}{\sqrt{(1-x^2)(1-k^2x^2)}},$$

$$\frac{dx'}{\sqrt{(1-x'^2)(1-k^2x'^2)}}=\frac{1}{M'}\frac{dy}{\sqrt{(1-y^2)(1-\lambda^2y^2)}}.$$

Hence, combining these equations and integrating,

$$F(kx')=\frac{1}{MM'}F(kx);$$

and it may also be shown that $\frac{1}{MM'}$ is an integer.

function of the modulus k which is usually denoted by q, and which occurs perpetually in this part of the theory of elliptic functions. If for the moment we denote this function by $\mathrm{F}k$, so that $q = \mathrm{F}k$, then if for k we write k_n, which we suppose to represent the modulus of the first real transformation of the nth order, we find that $q^n = \mathrm{F}k_n$, so that if q_n is the same function of k_n that q is of k

$$q_n = q^n.$$

This singular property, and others of an analogous character, are of great use in establishing various formulæ *.

Before discussing the evolution of integrals of the third kind, M. Jacobi has premised some important theorems. He proves that the elliptic integral of the third kind, though it involves three elements, viz. the amplitude, the modulus and the parameter, can yet be expressed in terms of other quantities severally involving but two. In order to this we introduce either a new transcendent † or a definite elliptic integral of the third kind, whose amplitude is a certain function of its modulus and parameter. It is almost impossible to tabulate the values of a function of three elements, on account of the enormous bulk of a table with *triple entry*; we therefore see the importance of the step thus made. M. Jacobi announced this discovery as generally true of elliptic integrals of the third kind, but his demonstration applies to that subdivision already mentioned, which was designated by Legendre "Fonctions du troisième ordre à parametre logarithmique," and not to functions "à parametre circulaire ‡." It is probable that this limitation was in M. Jacobi's mind, but he does not seem to have expressed it. Further on, in the 'Fundamenta Nova,' we find another mode of expressing integrals of the third kind in terms of functions of two elements, but this method also applies only to "fonctions du troisième ordre à parametre logarithmique," the two methods being in fact closely allied.

Legendre appreciated the importance of this discovery of M. Jacobi. He speaks of it in a letter to Abel, as a "découverte majeure," but adds that his attempts to extend M. Jacobi's demonstration to the other class of integrals of the third kind had been unsuccessful. The same remarks occur in his second supplement (Traité des Fonct. Ell., iii. p. 141). The distinction thus made between the two classes of integrals of the third kind appeared to Legendre sufficient to make it desirable to recognise in all four classes of elliptic integrals, so as to make the division between the two species of the third class coordinate with that between either and the first or second. Legendre says explicitly that M. Jacobi had announced, in making known his discovery, that it applied to functions "à parametre circulaire." This

* A method of calculating elliptic integrals by means of q was suggested by Legendre. Vide Verhulst, p. 252, and M. Jacobi in Crelle.

† This transcendent is denoted by τ, and is defined by the equation

$$\tau = \int \mathrm{E}(c\,\phi)\,\frac{d\,\phi}{\Delta(c\,\phi)},$$

where $\mathrm{E}(c\,\phi)$ is the elliptic integral of the second kind. If we introduce the inverse notation, and make $\phi = \mathrm{am}\,u$, we can readily establish the following result,

$$\tau = \frac{1}{2}u^2 - c^2 \iint \sin^2 \mathrm{am}\,u\,d\,u^2.$$

The function τ, which is the logarithm of Ω (vide *infra*, p. 66), has many remarkable properties.

‡ In the former species $(1+n)\left(1+\frac{c^2}{n}\right)$ is negative, and in the latter positive (vide *ante*, p. 45). The specific names are derived from the circumstance that for the former the fundamental formula of addition involves a logarithm, for the latter a circular arc.

however possibly arose from some misconception of M. Jacobi's meaning. Dr. Gudermann, in the fourteenth volume of Crelle's Journal, has given it as his opinion that the circular species of integrals of the third kind does not admit of the reduction in question; and remarks, that it occurs much more frequently than the other species in the applications of mathematics to natural philosophy.

After having discussed at some length, and by new methods, the properties of elliptic integrals of the third kind, M. Jacobi concludes his work by investigating the nature of two new transcendents which present themselves in immediate connexion with the numerator and denominator of the continued product by which sin am u is expressed. One of them however M. Jacobi had already recognised by a distinctive symbol, in consequence of its intimate connexion with the theory of integrals of the third kind.

Such is the outline of this remarkable work: before it appeared M. Jacobi gave in the third and fourth volumes of Crelle's Journal (iii. pp. 192, 303, 403, iv. p. 185) notices, mostly without demonstrations, of the progress of his researches. Almost everything in the first and second of these notices is found in the 'Fundamenta.' In the third we find a remarkable algebraical formula for the multiplication of the elliptic integral of the first kind. The fourth and last relates to ulterior investigations, which it was the intention of the author to develope in a second part of his work. It contains an indication of a method of transformation depending on a partial differential equation *; values of the elliptic functions of multiple arguments; a method of transforming integrals of the second and third kinds; a most important simplification of the method of Abel for the division of any integral of the first kind, &c. Of this simplification he had already given some idea in a note in the preceding volume of the same Journal, p. 86.

17. It may not be improper in this place to observe, that in 1818, and thus in the interval between Legendre's first and second systematic works on the theory of elliptic functions, M. Gauss published the tract entitled 'Determinatio Attractionis,' &c. The illustrious author begins by remarking that the secular inequalities due to the action of one planet on another are the same as if the mass of the disturbing planet were diffused according to a certain law along its orbit, so that the latter becomes an elliptic ring of variable but infinitesimal thickness. The problem then presents itself of determining the attraction exerted by such a ring on any external point. In the solution of this problem M. Gauss arrives at two definite integrals; they can readily be reduced to elliptic integrals of the first and second kinds. For the evaluation of the integrals to which he reduces those of his problem, M. Gauss gives a method of successive transformation, analogous in some measure to that of Lagrange. But the transformation of which he makes use is a rational one, and is in fact the rational transformation of the second order. The discovery of this transformation appears therefore to be due to M. Gauss. He has remarked, though merely in passing, that his method is applicable to the indefinite as well as to the definite integral. The rational transformation in question leads to a continually increasing series of moduli, or is, to use an expression of M. Jacobi a transformation "minoris in majorem." The law connecting two consecutive moduli is the same as in Lagrange's, which is, as we have seen, an irrational transformation; so that M. Gauss's method does not afford us a new scale of moduli. Nevertheless, as no rational transformation had I believe been noticed when his tract ap-

* Mr. Cayley, to whose kindness I have been, while engaged on the present report, greatly indebted, has communicated to me a demonstration of the truth of this equation.

peared *, his method is, in a historical point of view, of considerable interest.

18. In the second volume of Crelle's Journal, p. 101, we find Abel's first memoir on elliptic functions. It was published in the spring of 1827, and therefore before M. Jacobi's announcement in No. 123 of Schumacher's Journal. But it contains nothing which interferes with M. Jacobi's discovery of the general theory of transformation. Abel's researches on this part of the subject appeared in the third volume of Crelle's Journal, p. 160. This second communication is dated, as we are informed by an editorial note, the 12th of February, 1828, and though it is announced as a continuation of the former memoir, it is yet in effect distinct from it, as its contents are not mentioned in the general summary prefixed to the first communication.

These details may not be without interest, though it is not often that questions of priority deserve the importance sometimes given to them. There is no doubt that Abel's researches were wholly independent of those of M. Jacobi; and though the coincidence of some of their results is therefore interesting, yet the general view which they respectively took of the theory of elliptic functions is essentially different, as different as the style and manner of their writings.

With M. Jacobi the problem of transformation occupied the first place; with Abel that of the division of elliptic integrals. Both introduced a notation inverse to that which had previously been used, and as an immediate consequence recognised the double periodicity of elliptic functions. Expressions of these functions in continued products and series were given by both, but those of Abel were deduced by considering the limiting case of the multiplication of elliptic integrals, those of M. Jacobi, as we have seen, from the limiting case of their transformation. Hence Abel's fundamental expressions depend on doubly infinite continued products, corresponding to the double periodicity of elliptic functions. On the other hand, M. Jacobi's continued products are all singly infinite.

Other differences might of course be pointed out, but the most remarkable is that which we find in the character and style of their writings. Nothing can be more distinct. In M. Jacobi's we meet perpetually with the traces of patient and philosophical induction; we observe a frequent reference to particular cases and a most just and accurate perception of analogy. Abel's are distinguished by great facility of manner, which seems to result from his power of bringing different classes of mathematical ideas into relation with each other, and by the scientific character of his method. We meet in his works with nothing tentative, with but little even that seems like artifice. He delights in setting out with the most general conception of a problem, and in introducing successively the various conditions and limitations which it may require. The principle which he has laid down in a remarkable passage of an unfinished essay on equations seems always to have guided him—that a question should be so stated that it may be possible to answer it. When so stated it contains, he remarks, the germ of its solution †.

* The fundamental formula of his transformation is incidentally mentioned in Legendre's second work (Traité des Fonct., i. 61).

† For instance, Is it possible to trisect an angle by the rule and compass? The question thus stated leads us to consider the general character of all problems soluble by the methods of elementary geometry; and following the suggestion thus given, we find that it is to be answered in the negative. But if the last clause be omitted or neglected, we can only proceed, as many persons have done, tentatively, *i. e.* by attempting actually to solve the problem. If we fail, the question remains unanswered; if we succeed, we do answer it, but as it were only by accident.

I do not presume to compare the merits of these two mathematicians. The writings of both are admirable, and may serve to show that if ever the modern method of analysis seems to be an ἐμπειρία rather than a τέχνη, it does so, either because it has not been rightly used, or because it is not duly understood.

To obtain a general view of Abel's writings it may be remarked, that his earliest researches related to the theory of equations. Of the ideas with which he was then conversant he has made two principal applications. The one is to the comparison of transcendents in the manner already described; the other to the solution of the equations presented by the problem of the division of elliptic integrals. The second of these applications is contained in the memoir published in the second volume of Crelle's Journal.

He begins by introducing an inverse notation $\varphi(u)$ corresponding to the function denoted in the 'Fundamenta Nova' by sin am u, while $f(u)$ and $F(u)$ correspond respectively to cos am u and Δ am u. This notation has the defect of appropriating three symbols which we cannot well spare. On the other hand it is certainly more concise than M. Jacobi's.

He then verifies the fundamental formulæ for the addition of the new functions, and goes on to show that they are doubly periodic *. He next considers the expressions of $\varphi n\alpha$, &c. in $\varphi\alpha$, &c., and proceeds to prove the important proposition that the equation of the problem of the division of elliptic integrals of the first kind is always algebraically soluble.

In order to illustrate this, which is one of the most remarkable theorems in the whole subject, it may be observed, that as any circular function of a multiple arc can be algebraically expressed in terms of circular functions of the simple arc, so may $\varphi n\alpha$, $fn\alpha$, $Fn\alpha$ be algebraically expressed by means of $\varphi\alpha$, $f\alpha$, $F\alpha$.

Conversely, as the determination (to take a particular function) of $\sin\alpha$ in terms of $\sin n\alpha$ requires the solution of an algebraical equation, so does that of $\varphi\alpha$ in terms of $\varphi n\alpha$. The equation which presents itself in the former case is, as we know, of the nth or of the $(2n)$th degree as n is odd or even. But the equation for determining $\varphi\alpha$ rises to the (n^2)th degree in the former case, and in the latter to the $(2n^2)$th. We may however confine ourselves to the case in which n is a prime number; since if it be composite the argument of the circular or elliptic function may first be divided by one of the factors of n, and the result thus got by another, and so on. Thus setting aside the particular case of $n=2$, we shall have to consider, in order to determine $\sin\alpha$ or $\varphi\alpha$, an algebraical equation of the nth or (n^2)th degree respectively.

In consequence of the periodicity of $\sin\alpha$, the roots of the equation in $\sin\alpha$ admit of being expressed in a transcendental form; they are all included in the formula $\sin\left(\alpha+\frac{2p\pi}{n}\right)$, in which p is integral, and which therefore admits of only n different values.

* The formulæ in question differ from those already given, only because Abel's form of the elliptic integral is $\int\frac{dx}{\sqrt{(1-c^2x^2)(1+e^2x^2)}}$, which becomes the same as Legendre's on making $e^2=-1$. The double periodicity of the functions is expressed by the formula

$$\varphi\theta=\varphi\{(-1)^{m+n}\theta+m\omega+n\varpi\sqrt{-1}\},$$

with similar formulæ for f and F. The quantities m and n are integral, and

$$\omega=2\int_0^{\frac{1}{c}}\frac{dx}{\sqrt{(1-c^2x^2)(1+e^2x^2)}},\qquad \varpi=2\int_0^{\frac{1}{e}}\frac{dx}{\sqrt{(1+c^2x^2)(1-e^2x^2)}}.$$

But elliptic functions are *doubly* periodic, and therefore the roots of the equation in φa are expressible by a formula analogous to the one just written, but which involves two indeterminate integers corresponding to the two periodicities of the function, just as p does to the single periodicity 2π. Giving all possible values to these integers, we get n^2 different values for the formula.

The question now is, how are we to pass from the transcendental representation of these roots to their algebraical expression? Or, in other words, how are the relations among the roots deducible from the circumstance of their being all included in the same formula, to be made available in effecting the solution of the algebraical equation?

The answer to this question is to be found in the following principle: that if χu be such a rational function of u that

$$\chi x = \chi y = .. = \chi z,$$

$x, y, .. z$ being the roots of an algebraical equation, then any of these quantities may be expressed in terms of the coefficients of the equation. This follows at once from the consideration that we shall have

$$\chi x = \frac{1}{\mu}\{\chi x + \chi y + \ldots + \chi z\},$$

μ being the number of the roots $x, y, \ldots z$. For the sum within the bracket being a rational and symmetrical function of the roots, is necessarily expressible in the coefficients of the equation, and the same is therefore of course true of χx, or of any of the other quantities to which it is equal.

If, therefore, by means of the relations which we know to exist among the roots of the equation to be solved we can establish the existence of a system of such functions, χ, χ', χ'', &c., each of which retains the same value of whichever root we suppose it to be a function; and if by combining these functions we can ultimately express x in terms of them, the equation is solved, since each of these functions may be considered a known quantity.

Such is the general idea of Abel's method of solution. The principle on which it depends, namely, the expressibility of any unchangeable function χ, is one which is frequently met with in investigations similar to that of which we are speaking. M. Gauss's solution of the binomial equation is founded upon it.

I have already remarked that an important simplification of Abel's process was given by M. Jacobi. The result which M. Jacobi has stated without demonstration may be proved by means of a theorem established by Abel in the fourth volume of Crelle's Journal, p. 194.

M. Jacobi shows the existence of a system of n^2 functions χ, χ', &c., by combining which we can immediately express the values of the roots. In the last of his 'Notices' on elliptic functions we find, as has been said, the explicit determination of all the roots. The formula given for this purpose is, like the former, undemonstrated, and I do not know whether any demonstration of it has as yet been published; but from a note of M. Liouville, in a recent volume of the 'Comptes Rendus,' we find that both he and M. Hermite have succeeded in proving it.

But in whatever manner the solution is effected it will always involve certain transcendental quantities, which are introduced in the expressions of the relation subsisting between the different roots. The solution can therefore be looked on as complete, only if we consider these to be known quantities. They are the roots of a particular case of the equation to be solved. They relate to the division of what are called the complete integrals. We may therefore say that the general case is reduced to this particular one. But

the latter is not, except under certain circumstances, soluble, though the solution of the equation on which it depends can be reduced to the solution of certain other equations of lower degrees.

But for an infinity of particular values of the modulus, the case in question is soluble by a method closely analogous to that used by M. Gauss for the solution of binomial equations. Thus for all such values the problem of the division of elliptic integrals is completely solved.

The most remarkable of these cases corresponds to the geometrical problem of the division of the perimeter of the lemniscate. Abel discovered that this division can always be effected by means of radicals, and further, that it can be constructed by the rule and compass in the same cases (that is for the same values of the divisor) as the division of the circumference of a circle. Of this discovery we find Abel writing to M. Holmboe, "Ah qu'il est magnifique! tu verras*."

In order to form an idea of the nature of the difficulty which disappears in the case of which we are speaking, let us suppose that we have to solve the algebraical equation which is represented by the transcendental one $\varphi(3\theta) = 0$, in the same manner as the equation $4x^3 - 3x = 0$ is represented by $\sin(3\theta) = 0$.

The roots of $4x^3 - 3x = 0$, are, setting aside zero,

$$\sin\frac{2\varpi}{3},\ \sin\frac{4\varpi}{3}.$$

Those of the former algebraical equation, which, as we know, is of the ninth degree, are, beside zero,

$$\varphi\frac{2w}{3}, \qquad \varphi\frac{4w}{3}$$

$$\varphi\frac{2\varpi i}{3}, \qquad \varphi\frac{4\varpi i}{3}$$

$$\varphi\frac{2(w+\varpi i)}{3}, \qquad \varphi\frac{4(w+\varpi i)}{3}$$

$$\varphi\frac{2(w+2\varpi i)}{3}, \qquad \varphi\frac{4(w+2\varpi i)}{3},$$

where $i = \sqrt{-1}$.

To satisfy ourselves that these are the roots required, we observe that $\varphi(mw + n\varpi i) = 0$ for all integral values of m and n. Hence the general form of the roots of our equation is $\varphi\frac{mw + n\varpi i}{3}$; but it will be found that if we give any values not included in the above table to m and n, the resulting expression can be reduced to one or other of the forms we have specified in virtue of the formula $\varphi(\theta) = \varphi\{(-1)^{m+n}\theta + mw + n\varpi i\}$. *E.g.* The non-tabulated root $\varphi\frac{5w + 2\varpi i}{3}$ is equal to our sixth root $\varphi\frac{4(w+\varpi i)}{3}$, since the *sum* of their arguments is $3w + 2\varpi i$, and the sum of 3 and 2 is an *odd* number.

* It is right to mention that M. Libri has disputed Abel's title to the theory of the division of the lemniscate. I shall, however, not enter on the merits of the controversy which arose on this point between him and M. Liouville. The reader will find it in the seventeenth volume of the 'Comptes Rendus.' It appears that M. Gauss had himself recognised the applicability of his method to the equation arising out of the problem of the division of the perimeter of the lemniscate (vide Recherches Arithmetiques, § vii. p. 429. I quote from the translation published at Paris in 1809).

On considering our table, we observe that it consists of $3+1$ horizontal rows, each containing $3-1$ terms, and that the arguments of the terms in each row are connected by a simple relation; that of the second being double that of the first. If we were to replace 3 by any odd number p, we should get an equation of the p^2 degree, whose roots, setting aside zero, might similarly be arranged in $p+1$ rows, each of $p-1$ terms, the arguments of the terms in each row being as 1, 2, 3, &c.

Moreover, $\sin\frac{4\pi}{3}$ is rationally expressible in $\sin\frac{2\pi}{3}$, and generally $\sin\frac{2p\pi}{2n+1}$ is so in $\sin\frac{2\pi}{2n+1}$, n and p being any integers we please. So too are all the terms in each horizontal row of our table, whether for the particular case we have written down, or for that of any odd number, rationally expressible in the first term.

Hence it may be shown that when the divisor $2n+1$ is a prime number, an equation whose roots were the terms in any horizontal row could be solved algebraically, by a method essentially the same as that of Gauss, just as we can solve the equation the type of whose roots is $\sin\frac{2p\pi}{2n+1}$. But to construct this equation, *i. e.* to determine its coefficients, requires the solution of an equation of the same degree as the number of horizontal rows, *i. e.* of the degree $2n+2$. And this equation is in general insoluble. The difficulty we here encounter may be expressed in general language, by saying that although we can pass from one root to another along each horizontal row, yet we cannot pass from row to row.

Our table, however, has the remarkable property, that supposing, as we may always do, $2n+1$ to be a prime number, all the roots are rationally expressible in terms of any two not lying in the same row. This depends on a property of the function φ, which it is very easy to demonstrate, and it is intimately connected with the relations which exist among the terms of the same row.

If, then, which is the case for an infinite variety of values of the modulus, we can express any root rationally in terms of another of a different row, say in $\varphi\frac{2\omega}{2n+1}$, all the roots become rational in terms of $\varphi\frac{2\omega}{2n+1}$. Moreover, it appears that not only are the roots all expressible in one, but they are so in such a manner that the functional dependencies among them fulfil a certain simple condition, which, as Abel shows in a separate memoir (Crelle, iv. p. 131; or Abel's works, i. p. 114), renders every equation, all whose roots are rationally expressible in terms of one, algebraically soluble.

To take the simplest case, the arc of the lemniscate may be represented by the integral $\int\frac{dx}{\sqrt{1-x^4}}$. If φ be the function inverse to this integral, we have the simple relation between roots of different rows, $\varphi\frac{2\omega i}{2n+1}=i\varphi\frac{2\omega}{2n+1}$, ω being in this case equal to ϖ.

To apply what has been said to the solution of the general equation for determining φa in terms of $\varphi(2n+1)a$, it is sufficient to remark that the transcendents introduced in considering the relations among the roots of this equation, are simply $\varphi\frac{2\omega}{2n+1}$ and $\varphi\frac{2\omega i}{2n+1}$, or at least may be algebraically expressed in terms of these two quantities.

The remainder of the first memoir contains developments of the functions

to the integral $\int \frac{du}{\sqrt{(1-u^2)(1-k^2u^2)}}$, and φ_c the corresponding function for the modulus c, then, on introducing the inverse notation, the differential equation

$$\frac{dy}{\sqrt{(1-y^2)(1-k^2y^2)}} = a\frac{dx}{\sqrt{(1-x^2)(1-c^2x^2)}}$$

becomes of course $d\theta' = a\,d\theta$, with $x = \varphi_c\theta$ and $y = \varphi_k\theta'$. Hence for a given increment α of θ, that of θ' is $a\alpha$.

Let us take the simplest case, and suppose y to be a rational function of x; then, as x or $\varphi_c\theta$ remains unchanged when θ increases by a period of the function φ_c, y does so too; that is $\varphi_k\theta'$ remains unchanged when θ' increases by a times a period of φ_c, or in other words, a times a period of φ_c is necessarily one of φ_k.

Suppose now k and c to be both real and less than unity; then φ_k and φ_c have each a real period, here denoted by $2\omega_k$ and $2\omega_c$ respectively, and each an imaginary period $\varpi_k i$ and $\varpi_c i$ respectively, ϖ_k and ϖ_c being both real. Let θ receive first the increment $2\omega_c$, and secondly the increment $\varpi_c i$, then, by what has been said,

$$2a\omega_c = 2m\omega_k + n\varpi_k i$$

$$a\varpi_c i = 2p\omega_k + q\varpi_k i^*,$$

m, n, p, q being certain integers. But can these two equations subsist simultaneously? Not generally, since if we eliminate a and equate possible and impossible parts, we get *two* relations among ω_c ϖ_c ω_k ϖ_k, which are continuous functions of the *two* quantities k and c. Hence *both* are determinate; and if we wish c to remain indeterminate, we must either make m and q equal to zero, in which case a is impossible, or, making n and p equal to zero, assign a real value to it. When a is real we have

$$a = m\frac{\omega_k}{\omega_c} = q\frac{\varpi_k}{\varpi_c},$$

and hence the remarkable conclusion, that

$$\frac{\omega_k}{\varpi_k} : \frac{\omega_c}{\varpi_c} :: q : m,$$

m and q being integers.

The commensurability of the transcendental functions $\frac{\omega_k}{\varpi_k}$, $\frac{\omega_c}{\varpi_c}$ is therefore a necessary condition, in order that an integral with modulus c can be transformed into one with modulus k, the *regulator* a being real and c indeterminate. And it may be shown that this condition is not only necessary but sufficient. Similar considerations apply to the case in which a is impossible.

Simple as this view is, it leads to many consequences of great interest. The function q, of which we have already spoken (p. 55), is merely $e^{-\pi\frac{\varpi}{\omega}}$, and as we know for the first real transformation of the nth order, it becomes $e^{-\pi\frac{n\varpi}{\omega}}$. Hence in this case we have $\left[\frac{\varpi}{\omega}\right]_k = n\left[\frac{\varpi}{\omega}\right]_c$ according to the general law. It may be well to remark, that if $k = c$ we have $a = m\frac{\omega_k}{\omega_c} = m$

* ϖ here is in M. Jacobi's notation $2K'$, so that $\varphi\theta = \varphi(\theta + 2m\omega + n\varpi i)$, m and n being any integers.

(an integer). Hence in *multiplying* an integral, the multiplier must be an integer, if y is rational in x, except for particular values of c.

In the paper of which we are speaking Abel has applied precisely similar considerations to the case in which x and y are connected by any algebraical equation.

Passing over one or two shorter papers, one of which has been already referred to at p. 59, we come to a 'Précis' of the theory of elliptic functions, published in the fourth volume of Crelle's Journal, p. 236. The work of which it was designed to be an extract was never written, and the 'Précis' itself is left unfinished. A general summary was prefixed to it, from which we learn that the work was to be divided into two parts. In the first elliptic integrals are considered irrespectively of the limits of integration, and their moduli may have any values, real or imaginary. Abel proposes the general problem of determining all the cases in which a linear relation may exist among elliptic integrals and logarithmic and algebraical functions in virtue of algebraical relations existing among the variables*.

His first step is to apply his general method for the comparison of transcendents to elliptic integrals, which may be done by what is called Abel's theorem, in at least two different ways: the one, that of which he now makes use; the other, that which we have seen is applied to the case of four functions by Legendre in his third Supplement.

He next determines the most general form of which the integral of an algebraical differential expression of any number of variables is capable, provided it can be expressed linearly by elliptic integrals and logarithmic and algebraical functions. The result at which he arrives admits of many important applications. It is, that the integral in question may be expressed in a form in which the sine of the amplitude of each elliptic integral and the corresponding Δ, and also the algebraical and each logarithmic function are all *rational* functions of the variables and of the differential coefficients of the integral with respect to each.

He proceeds by an interesting train of reasoning to establish the remarkable conclusion, that the general problem which we are considering may ultimately be reduced to that of the transformation of elliptic integrals of the first kind. The problem of this transformation is then discussed, and by a method essentially the same as that of which he had made use in his paper in Schumacher's Journal. The appearance however of the two investigations is dissimilar, because no reference is made to elliptic functions (as distinguished from elliptic integrals) in the first part of the 'Précis.' The relations therefore which exist among the roots of $y=\psi x$ are established by considerations independent of the periodicity of elliptic functions; though it is not difficult to perceive that they were *suggested* by the results previously obtained by means of that fundamental property. It is shown, that if the equation $y=\psi x$, where ψx is a rational function, satisfy the differential equation (A.), then this equation, considered as determining x in terms of y, is always algebraically soluble. As the multiplication of elliptic integrals may be considered a case of transformation (that, namely, in which the modulus of the transformed integral remains unchanged), this theorem may be looked on as an extension of that which we have spoken of (p. 58) in giving an account of Abel's first memoir on elliptic functions. The two theorems are proved by the same kind of reasoning.

The second part of the memoir was to have related to cases in which the moduli are real and less than unity; of this however only the summary exists.

* In the assumed relation, the amplitude, or rather the sine of the amplitude of each elliptic integral, is to be one of the variables, and *not* a function of one or more of them.

Abel proposed to introduce three new functions, the first corresponding to that which he had previously designated by $\varphi\theta$*. He now denotes it by $\lambda\theta$. The second and third functions are apparently what the second and third kind of elliptic integrals respectively become, when, instead of x, we introduce the new variable θ; x and θ being of course connected by the equation $x = \lambda\theta$. The double periodicity of the function λ and its other fundamental properties having been established, it was his intention to proceed to more profound researches. Some of his principal results are briefly stated. I may mention one, that all the roots of the modular equation may be expressed rationally in terms of two of them†.

One of the last paragraphs of the summary relates to functions very nearly identical with those which M. Jacobi discusses at the close of the 'Fundamenta Nova,' and which he has designated by the symbols H and Θ.

The second volume of Abel's collected works consists of papers not published during his life. Two or three of these relate to elliptic functions. The longest contains a new and very general investigation for the reduction of the general transcendent, whose differential is of the form $\frac{P}{\sqrt{R}}$, P being, as usual, rational and R a polynomial of the fourth degree; together with transformations with respect to the parameter of integrals of the third kind.

20. Having now given some account of the revolution which the discoveries of Abel and Jacobi produced in the theory of elliptic functions, I shall mention some of the principal contributions which have been made towards the further development of the subject since the publication of the 'Fundamenta Nova.' In Crelle's Journal, iv. p. 371, we find a paper by M. Jacobi, entitled 'De Functionibus Ellipticis Commentatio.' It contains, in the first place, a development of the method of transforming elliptic integrals of the second and third kind, and introduces a new transcendent Ω, which takes the place of Θ, with which it is closely connected. M. Jacobi proves that the numerator and denominator of the value of y, mentioned above, and which have been denoted by U and V, satisfy a single differential equation of the third order. The remainder of the paper relates to the properties of Ω (vide *ante*, note, p. 55). When this function is multiplied by a certain exponential factor it becomes a singly periodic function, and, which is very remarkable, its period is equal to one of the single or composite periods of the elliptic function inverse to the integral of the first kind. By composite period I mean the sum of multiples of the fundamental periods. The exponential factor being properly determined, its product by Ω is equal to Θ multiplied by a constant. In considering this subject M. Jacobi is led to introduce the idea of conjugate periods. These are periods by the combination of which all the composite periods may be produced. It is obvious that the fundamental periods are conjugate periods; and there are, as may easily be shown, an infinity of others.

In the sixth volume of the same journal we find a second part of the 'Commentatio.' It contains a remarkable demonstration of the fundamental

* In the 'Précis' Abel has adopted the canonical form of the integral of the first kind made use of by Legendre and M. Jacobi; so that the quantity under the radical is $(1-x^2)(1-c^2x^2)$. It is worth remarking, that in his first paper in Schumacher's Nachrichten this quantity is $(1-e^2x^2)(1-c^2x^2)$, while in the second it is the same as in the 'Précis.' To this form he appears latterly to have adhered.

† It is not clear whether by roots of the modular equation we are to understand the transformed moduli themselves, or their fourth roots, *i. e.* in M. Jacobi's notation λ or ν. Vide *supra*, p. 50.

formulæ of transformation of the odd orders founded on elementary properties of elliptic functions.

In a historical point of view a notice by M. Jacobi in the eighth volume of Crelle (p. 413) of the third volume of Legendre's 'Traité des Fonctions Elliptiques' is interesting. It was here, I believe, that M. Jacobi first proposed the name of Abelian integrals for the higher transcendents, which we shall shortly have occasion to consider. After some account of the contents of Legendre's supplements, the first two of which contain the greater part of M. Jacobi's earlier researches, he goes on to generalise a remarkable reduction given by Legendre at the close of his work.

21. I turn to one of the very few contributions which English mathematicians have made to the subject of this report, namely, to a paper by Mr. Ivory, which appeared in the Phil. Trans. for 1831. His design is to give in a simple form M. Jacobi's theorem for transformation. The demonstration is essentially the same as that in the 'Fundamenta Nova.' But Mr. Ivory does not set out with assuming $y = \frac{U}{V}$, U and V being integral functions of x, but with assuming it equal to the continued product of a number of elliptic functions (whose arguments are in arithmetical progression), multiplied by a constant factor. This is one of M. Jacobi's transcendental expressions for y, and the two assumptions are therefore perfectly equivalent in the transformations of odd orders; but in those of even orders, or where the continued product consists of an even number of factors, Mr. Ivory's amounts to making y equal to an irrational function of x. Transformations by irrational substitutions, though long the only kind known (since Lagrange's belongs to this class), had not of late been considered in detail. Abel indeed remarked in the beginning of the general investigation contained in Schumacher's Journal (No. 138), that the existence of an irrational transformation implied that of a rational one leading to an integral with the same modulus as the other. He was, therefore, in seeking for the most general modular transformation, exempted from considering irrational substitutions; but in a historical point of view it is interesting to see the connection between Lagrange's transformation and those which have been more recently discovered*.

* If $y=(1+b)\,x\sqrt{\frac{1-x^2}{1-c^2x^2}}$, where $b^2+c^2=1$, then

$$\frac{dy}{\sqrt{(1-y^2)(1-k^2y^2)}} = (1+b)\,\frac{dx}{\sqrt{(1-x^2)(1-c^2x^2)}}$$

where $$k=\frac{1-b}{1+b}.$$

This is Lagrange's *direct* transformation. The corresponding rational transformation is

$$y=\frac{1-(1+b)\,x^2}{1-(1-b)\,x^2},$$

which satisfies the same differential equation as before.

Again, $$\frac{dy}{\sqrt{(1-y^2)(1-k^2y^2)}} = \frac{1+c}{2}\,\frac{dx}{\sqrt{(1-x^2)(1-c^2x^2)}},$$

where $$k=\frac{2\sqrt{c}}{1+c}$$

is satisfied by $$2y^2=1+c\,x^2-\sqrt{(1-x^2)(1-c^2x^2)},$$

which may be called Lagrange's *inverse* transformation, k being now the same function of c, that c was before of k. The corresponding rational transformation is

$$y=\frac{(1+c)\,x}{1+c\,x^2},$$

The question presents itself, what is the connection between the irrational transformation (that of which Lagrange's is a particular case) and the rational transformation of even orders? Perhaps the simplest answer to it (though every question of the kind is included in the general investigations contained in Abel's 'Précis') is found in a paper by M. Sanio in the fourteenth volume of Crelle's Journal, p. 1. The aim of this paper is to develope more fully than Mr. Ivory has done the theory of transformations of even orders, and particularly of the irrational transformations, which M. Sanio considers more truly analogous to the rational transformations of odd orders than the rational transformations of even orders; and also to discuss the multiplication of elliptic integrals by even numbers, a subject intimately connected with the other. We have already mentioned the existence of what are called complementary transformations, each of which may be derived from the other by an irrational substitution, by which two new variables are introduced. In the case of transformations of odd orders, the original transformation and the complementary one are both rational, and are both included in the general formula given by M. Jacobi's theorem; but to the rational transformation of any even order corresponds as its complement the irrational transformation of the same order. This remark, which, as far as I am aware, had not before been made, sets the subject in a clear light*.

22. In the twelfth volume of Crelle's Journal (p. 173), Dr. Guetzlaff has investigated the modular equation of transformations of the seventh order: it is, as we know from the general theory, of the eighth degree, and presents itself in a very remarkable form, which closely resembles that in which M. Jacobi, at p. 68 of the 'Fundamenta Nova,' has put the modular equation for the third order. Dr. Sohncke has given, at p. 178 of the same volume, modular equations of the eleventh, thirteenth and seventeenth orders, none of which apparently can be reduced to so elegant a form as those of the third and seventh. Possibly the transformation of the thirty-first order might admit of a corresponding reduction. The whole subject of modular equations is full of interest. Dr. Sohncke has demonstrated his results in a subsequent volume of the Journal (xvi. 97).

In the fourteenth volume of Crelle's Journal there is a paper by Dr. Gudermann on methods of calculating and reducing integrals of the third kind. I have already quoted from this paper the expression of the opinion of its learned author, that it is impossible to express the value of integrals of the circular species in terms of functions of two arguments. If this be so, it is

which is M. Gauss's, and is termed in M. Jacobi's nomenclature the rational transformation of the second order. It satisfies the equation

$$\frac{dy}{\sqrt{(1-y^2)(1-k^2y^2)}} = (1+c)\frac{dx}{\sqrt{(1-x^2)(1-c^2x^2)}},$$

where, as before,

$$k = \frac{2\sqrt{c}}{1+c}.$$

* Lagrange's transformation being

$$y = (1+b)x\sqrt{\frac{1-x^2}{1-c^2x^2}},$$ let $y = \frac{\sqrt{-1}\,y'}{\sqrt{1-y'^2}}$ and $x = \frac{\sqrt{-1}\,x'}{\sqrt{1-x'^2}}$,

then we find that

$$y' = \frac{(1+b)x'}{1+bx'^2},$$

while the differential equation becomes

$$\frac{dy'}{\sqrt{(1-y'^2)(1-k^2y'^2)}} = (1+b)\frac{dx'}{\sqrt{(1-x^2)(1-b^2x'^2)}},$$

where

$$k^2 = 1-k^2.$$

impossible to tabulate such integrals, and therefore our course is to devise series more or less convenient for determining their values when any problem, *e. g.* that of the motion of a rigid body, to which Dr. Gudermann especially refers, requires us to do so. The formation of such series is accordingly the aim of this memoir, which contains some remarkably elegant formulæ; one of which connects three integrals of the third kind with three of the second.

In the sixteenth and seventeenth volumes of the same Journal, Dr. Gudermann has given some series for the development of elliptic integrals; and he has since published in the same Journal a systematic treatise on the theory of modular functions and modular integrals, these designations being used to denote the transcendents more generally called elliptic. The point of view from which he considers the subject has been already indicated (vide *supra*, p. 36). In a systematic treatise there is of course a great deal that does not profess to be original, and it is not always easy to discover the portions which are so. Dr. Gudermann's earlier researches are embodied and developed in his larger work; and in some of the latter chapters (XXIII. 329, &c.) we find some interesting remarks on the forms assumed by the general transcendent when the biquadratic polynomial in the denominator has four real roots. Dr. Gudermann points out the existence of a species of correlation between pairs of values of the variable.

23. The development of the elliptic function φ in the form of a continued product may be applied to establish formulæ of transformation. This mode of investigating such formulæ was made use of by Abel in his second paper in Schumacher's Journal, No. 148, which we have already noticed; and a corresponding method is mentioned by M. Jacobi in one of the cursory notices of his researches which he inserted in the early volumes of Crelle's Journal. Mr. Cayley, in the Philosophical Magazine for 1843, has pursued a similar course. Another and very remarkable application of the same kind of development consists in taking it as the definition of the function φ, and deducing from hence its other properties. It has been remarked that the continued products of Abel and M. Jacobi are derived from considerations which, although cognate, are yet distinct; those of the latter being singly infinite, while Abel's fundamental developments consist of the product of an infinite number of factors, each of which in its turn consists of an infinite number of simple factors. Thus we can have two very dissimilar definitions of the function φ by means of continued products. M. Cauchy, who has investigated the theory of what he has termed reciprocal factorials, that is, of continued products of the form

$$\{(1+x)(1+tx)\ldots\ldots\}\{(1+tx^{-1})(1+t^2x^{-1})\ldots\ldots\},$$

which is immediately connected with M. Jacobi's developments, has accordingly set out from the singly infinite system of products, and has deduced from hence the fundamental properties of elliptic functions (Comptes Rendus, xvii. p. 825).

Mr. Cayley, on the other hand, has made use of Abel's doubly infinite products, and has shown that the functions defined by means of them satisfy the fundamental formulæ mentioned in the note at page 52, which, as these equations furnish a sufficient definition of the elliptic functions, is equivalent to showing that the continued products are in reality elliptic functions. He has therefore effected for Abel's developments that which M. Cauchy had done for M. Jacobi's. Mr. Cayley's paper appeared in the fourth volume of the Cambridge Mathematical Journal, but he has since published a translation of it with modifications in the tenth volume of Liouville's. On the

same subject we may mention a paper by M. Eisenstein (Crelle's Journal, xxvii. 285).

24. M. Liouville has in several memoirs investigated the conditions under which the integral of an algebraical function can be expressed in an algebraical, or, more generally, in a finite form. This investigation is of the same character as that which occurs in the beginning of Abel's last published memoir on elliptic functions (vide *supra*, p. 65). But while Abel's researches are more general than M. Liouville's, the latter has arrived at a result more fundamental, if such an expression may be used, than any of which Abel has left a demonstration.

He has shown that if y be an algebraical function of x, such that $\int y\,dx$ may be expressed as an explicit finite function of x, we must have

$$\int y\,dx = t + \mathrm{A}\log u + \mathrm{B}\log v + \ldots + \mathrm{C}\log w,$$

A, B, ... C being constant, and $t, u, v, \ldots w$ algebraical functions of x. The theorem established by Abel in the memoir referred to includes as a particular case the following proposition, that if

$$\int y\,dx = t + \mathrm{A}\log u + \mathrm{B}\log v + \ldots + \mathrm{C}\log w,$$

then $t, u, v, \ldots w$ may all be reduced to rational functions of x and y.

Combining these two results, it appears that if $\int y\,dx$ be expressible as an explicit finite function of x, its expression must be of the form

$$t + \mathrm{A}\log u + \mathrm{B}\log v + \ldots + \mathrm{C}\log w,$$

where $t, u, v, \ldots w$ are rational functions of x and y, or rather that its expression must be reducible to this form*.

After establishing these results in the memoir (that on elliptic transcendents of the first and second kinds), which will be found in the twenty-third cahier of the 'Journal de l'Ecole Polytechnique,' p. 37, M. Liouville supposes y to be of the form $\frac{\mathrm{P}}{\sqrt{\mathrm{R}}}$, where P and R are integral polynomials, and hence deduces the general form in which the integral $\int \frac{\mathrm{P}}{\sqrt{\mathrm{R}}}\,dx$ may necessarily be put, provided it admit of expression as an explicit finite function of x.

He shows from hence that if $\int \frac{\mathrm{P}}{\sqrt{\mathrm{R}}}\,dx$ cannot be expressed by an algebraical function of x, it cannot be expressed by any explicit finite function of it, and finally demonstrates that an elliptic integral, either of the first or second kind, is not expressible as an explicit finite function of its variable.

In a previous memoir inserted in the preceding cahier, M. Liouville proved the simpler proposition, that elliptic integrals of the first and second kinds are not expressible as explicit algebraical functions of their variable (Journal de l'Ecole Polytechnique, t. xiv. p. 137). His attention appears to have been directed to this class of researches by a passage of Laplace's 'Theory of Probabilities,' in which the illustrious author, after indicating the fundamental, and, so to speak, ineffaceable distinctions between different classes of functions, states that he had succeeded in showing that the integral $\int \frac{dx}{\sqrt{1+\alpha x^2+\beta x^4}}$ is not expressible as a finite function, explicit or implicit, of x. Laplace however did not publish his demonstration.

* An equivalent theorem is stated by Abel in his letter to Legendre for implicit as well as explicit functions (Crelle's Journal, vi.).

In his own Journal (v. 34 and 441), M. Liouville has since shown that elliptic integrals of the first and second kinds, considered as functions of the modulus, cannot be expressed in finite terms.

25. In the eighteenth volume of the 'Comptes Rendus' (Liouville's Journal, ix. 353), we find in a communication from M. Hermite, of which we shall shortly have occasion to speak more fully, a remarkable demonstration of Jacobi's theorem. It is stated for the case of the first real transformation, but might of course be rendered general. This demonstration depends essentially on the principle already mentioned (p. 59), that any rational function of a root of an algebraical equation which has the same value for every root of the equation is rationally expressible in the coefficients. The equation to which this principle is applied is that to which we have so often referred, viz. $y = \frac{U}{V}$, considered as an equation to determine x in terms of y, and by means of it, M. Hermite shows at once that a certain rational function of x is also a rational function of y, the form of which is subsequently determined.

M. Hermite goes on to prove other theorems relating to elliptic functions. As elliptic functions are doubly periodic, we may determine certain of their properties by considering to what conditions doubly periodic functions must be subject. This view is mentioned by M. Liouville in a verbal communication to the Institute (Comptes Rendus, t. xix.). He states that he had found that a doubly periodic function which is not an absolute constant and has but one value for each value of its variable must be, for certain values of it, infinite; that from hence the known properties of elliptic functions are easily deduced; and that by means of this principle he had succeeded in proving the expressions of the roots of the equation for the division of an elliptic integral of the first kind, which M. Jacobi had given without demonstration in Crelle's Journal*. I am not aware that any development of M. Liouville's view has as yet appeared.

In the recent numbers of Crelle's Journal there are many papers by M. Eisenstein on different points in the theory of elliptic functions. Among these I may mention one which contains a very ingenious proof of the fundamental formula for the addition of two functions, derived from the differential equation of the second order, which each function must satisfy.

Other contributions to the theory of elliptic functions might be mentioned; some of these, not here noticed, are referred to in the index which will be found at the end of this report. But in general it may be remarked that the form which the subject has assumed, in consequence of the discoveries of Abel and M. Jacobi, is that which it will probably always retain, however our knowledge of particular parts of it may increase. What has since been effected relates for the most part to matters of detail, of which, however important they may be, it is difficult or impossible to give an intelligible account.

26. It does not fall within the design of this report to consider the various applications which have been made of the theory of elliptic functions; but I shall briefly mention some of the geometrical interpretations, if the expression may so be used, which mathematicians have given to the analytical results of the theory.

The lemniscate has, as is well known, the property that its arcs may be represented by an elliptic integral of the first kind, the modulus of which is

* M. Liouville has mentioned that M. Hermite had demonstrated the formulæ in question in a different manner.

$\frac{1}{\sqrt{2}}$. The problem of the division of its perimeter is accordingly a geometrical interpretation of that of the division of the complete integral, and was considered by mathematicians at a time when the theory of elliptic functions was almost wholly undeveloped. Besides Fagnani, whose researches with respect to the lemniscate have been already noticed, we may mention those of Euler, who however did not succeed in obtaining a solution of the problem. Legendre, who seems to have attached considerable importance to geometrical illustrations of his analytical results, assigned the equation of a curve of the sixth order, whose arcs measured from a fixed point represent the sum of any elliptic integral of the first kind and an algebraical expression. He showed also that an arc of the curve might be assigned equal to the elliptic integral, but in order to this both extremities of the arc must be considered variable, so that in effect the integral is represented by the difference of two arcs measured from a fixed point (Traité des Fonctions Elliptiques, i. p. 36).

M. Serret, in a note presented to the Institute in 1843 (Liouville's Journal, viii. 145), has proved a beautiful theorem, viz. that the sum and difference of the two unequal arcs, intercepted by lines drawn from the centre of Cassini's ellipse to cut the curve, are each equal to an elliptic integral of the first kind, and that the moduli of the two integrals are complementary. In the lemniscate, which is a case of Cassini's ellipse, one of these arcs disappears, and the moduli of the two integrals are equal, each being the sine of half a right angle. So that M. Serret's theorem is an extension of the known property of the lemniscate.

M. Serret has since considered the subject of the representation of elliptic and hyper-elliptic arcs in a very general manner. His memoir, which was presented to the Institute and ordered to be published in the 'Savans Etrangers,' appears in Liouville's Journal, x. 257. He had remarked that the rectangular coordinates of the lemniscate are rationally expressible in terms of the argument of the elliptic integral which represents the arc, for if we assume $x = \sqrt{2}\,a\frac{z+z^3}{1+z^4}$ and $y = \sqrt{2}\,a\frac{z-z^3}{1+z^4}$, we shall have $ds = \sqrt{\{dx^2 + dy^2\}} = 2a\frac{dz}{\sqrt{1+z^4}}$, and if between the first two of these equations we eliminate z, we arrive at the known equation of the lemniscate*. So that if we state the indeterminate equation

$$dx^2 + dy^2 = Z.\,dz^2,$$

(x, y and Z being real and rational functions of z), the lemniscate will afford us one solution of it; and every other solution will correspond to some curve whose arc is expressible by an elliptic or hyper-elliptic integral. Of this indeterminate equation M. Serret discusses a particular case. He succeeds in solving it by a most ingenious method, which is applicable to the general equation, and shows from hence that there are an infinity of curves, the arcs of which represent elliptic integrals of the first kind. M. Serret's researches however have not led him to a geometrical representation by means of an *algebraical* curve of *any* integral of the first kind, though his results are generalised in a note appended to his memoir by M. Liouville. In order that

* On reducing the integral $\int\frac{dz}{\sqrt{1+z^4}}$ to the standard form of elliptic integrals, we find that it is an elliptic integral of the first kind, of which the modulus is the sine of 45°.

the curve may be algebraical, it is necessary and sufficient, as M. Liouville has remarked, that the square of the modulus of the integral should be rational, and less than unity.

In a subsequent memoir (Liouville's Journal, x. 351) he has very much simplified the analytical part of his researches, and in the same Journal (x. 421) has proved some remarkable properties of one class of what may be called elliptic curves. In the fourth number of the Cambridge and Dublin Mathematical Journal (p. 187), M. Serret has developed this part of the subject, and has also given a general sketch of his previous papers. M. Liouville (Comptes Rendus, xxi. 1255, or his Journal, x. 456) has given a very elegant investigation of an analytical theorem established by M. Serret.

In the fourteenth volume of Crelle's Journal (p. 217), M. Gudermann has considered the rectification of the curve called the spherical ellipse, which is one of a class of curves formed by the intersection of a cone of the second order with a sphere. He has shown that its arcs represent an elliptic integral of the third kind.

In the ninth volume of Liouville's Journal (p. 155), Mr. W. Roberts proves that a cone of the second order, whose vertex lies on the surface of a sphere, and one of whose external axes passes through the centre, intersects the sphere in a curve whose arcs will, according to circumstances, represent any elliptic integral of the third kind and of the circular species; or any elliptic integral of the same kind and of the logarithmic species, provided the angle of the modulus is less than half a right angle; or (subject to the same condition) any elliptic integral of the first kind; or lastly, by a suitable modification, any elliptic integral of the second kind. The cases here excepted may be avoided by introducing known transformations. The cases in which the arcs represent elliptic integrals of the first kind, Mr. Roberts has previously mentioned in the eighth volume of Liouville's Journal (p. 263). He has since given in the same Journal (x. 297), a general investigation of the subject, in which it is supposed that the vertex of the cone may have any position we please. M. Verhulst has represented the three kinds of elliptic integrals by means of sectorial areas of certain curves, and the function Υ by the volume of a certain solid. It is manifest, however, that it is incomparably easier to do this than to represent these transcendents by means of the arcs of curves.

Beside one or two other papers I may mention a tract by the Abbé Tortolini, on the geometrical representation of elliptic integrals of the second and third kinds. This tract, however, I have not seen.

Lagrange long since proved (vide Théorie des Fonctions Analytiques, p. 85), that by means of a spherical triangle a geometrical representation of the addition of elliptic integrals of the first kind may easily be obtained, and that hence by a series of such triangles we are enabled to represent the multiplication as well as the addition of these integrals.

M. Jacobi has given (Crelle's Journal, iii. p. 376, or vide Liouville's Journal, i. p. 435) a geometrical construction for the addition and multiplication of elliptic integrals of the first kind. It is founded on the properties of an irregular polygon inscribed in a circle, and the sides of which touch one or more other circles. It is to be remarked that Legendre, in giving an account of this construction in one of the supplements to his last work, has only considered its application to multiplication and not to addition, and has been followed in this respect by M. Verhulst, whose treatise on elliptic functions has been already mentioned. In consequence of this, M. Chasles was led to believe that until the publication of his own researches, no construction for addition excepting that of Lagrange was known. But he has recently

(Comptes Rendus, January 1846) pointed out the error into which he had fallen.

27. In the Transactions of the Royal Irish Academy (ix. p. 151), Dr. Brinkley gave a geometrical demonstration of Fagnani's theorem with respect to elliptic arcs, and in the sixteenth volume of the same Transactions (p. 76), we find Landen's theorem proved geometrically by Professor MacCullagh.

M. Chasles has considered the subject of the comparison of elliptic arcs by geometrical methods, and with great success. His fundamental proposition may be said to be, that if from any two points of an ellipse we draw two pairs of tangents to any confocal ellipse, the difference of the two arcs of the latter respectively intercepted by each pair of tangents is rectifiable. Or, what in effect is the same thing, if we fasten a string at two points in the circumference of an ellipse, and suppose a ring to move along the string, keeping it stretched, and winding it on and off the arc which lies between its two extremities, the ring will trace out a portion of an ellipse confocal to the former. If for the first ellipse we substitute an hyperbola confocal with the second, the *sum* of the arcs will be constant. From hence a series of theorems is deduced, remarkable not only for their elegance, but also for the facility with which they are obtained. They furnish constructions for the addition and multiplication of elliptic integrals. The whole of this investigation, of which an account is given in the 'Comptes Rendus' (vol. xvii. p. 838, and vol. xix. p. 1239), shows, like others of M. Chasles's, how much is lost in treating geometrical questions by an exclusive adherence to what may be called the method of co-ordination. Invaluable as this method is, it yet often introduces considerations foreign to the problem to which it is applied*.

III.

28. The first outline of a detailed theory of the higher transcendents was given by Legendre in the third supplement to his 'Traité des Fonctions Elliptiques.' He proposes to classify the transcendents comprised in the general formula

$$\int \frac{f(x)\,dx}{(x-\alpha)\sqrt{\varphi x}}$$

according to the degree of the polynomial φx, the first class being that in which the index of this degree is three or four; the second that in which it is five or six, and so on. The first class therefore consists of elliptic integrals; all the others may be designated as *ultra-elliptic*. This epithet, however, which was proposed by Legendre, has not been so generally used as *hyper-elliptic*, which was, I believe, first used by M. Jacobi. M. Jacobi, however, has proposed to call the higher transcendents Abelian integrals.

The principle of Legendre's classification is to be found in the minimum number of integrals to which the sum of any number of them can be reduced. As we know, this number is unity in the case of elliptic integrals, and by Abel's theorem we find that it is two in the first class of the higher transcendents, three in the next, and so on.

Following the analogy of elliptic integrals, Legendre proposed to recognise three canonical forms in each class of hyper-elliptic integrals, and thus to divide it into three orders. The sum of any number of functions of the first

* M. Chasles has also considered the subject of spherical conics, as well as that of the lines of curvature and shortest lines on an ellipsoid. The latter has recently engaged the attention of several distinguished mathematicians—MM. Jacobi, Joachimsthal, Liouville, MacCullagh and M. Roberts may be particularly mentioned.

kind will, when the required conditions are satisfied, be equal to a constant; that of any number of the second and third kinds respectively will, under similar conditions, be equal to an algebraical or logarithmic function.

Much the greater part of the remainder of the supplement consists of a *discussion* of the particular transcendents

$$\int \frac{dx}{\sqrt{1-x^5}} \quad \text{and} \quad \int \frac{dx}{\sqrt{1+x^5}}.$$

It contains a multitude of numerical calculations, and if the writer's age be considered (he was then almost eighty), is a very remarkable production. By means of the numerical calculations he recognised, as it were empirically, the values to be assigned in different cases to the above-mentioned constant: what these values ought to be, he did not attempt to determine *à priori*.

At the close of the supplement we find a remarkable reduction of an integral, apparently of a higher order to elliptic integrals. The method employed has been generalised by M. Jacobi, in a notice of Legendre's 'Supplements,' inserted in the eighth volume of Crelle's Journal (p. 413).

29. In the ninth volume of Crelle's Journal (p. 394), we find a most important paper by M. Jacobi (Considerationes Generales, &c.), which may be said to have determined the direction in which the researches of analysts in the theory of algebraical integrals were to proceed.

The writer proposes two questions, both suggested by the cases of trigonometrical and elliptic functions. First, as in these cases we consider certain functions to which circular and elliptic integrals are respectively inverse, and which are such that functions of the sum of two arguments are algebraically expressible in terms of functions of the simple arguments, what are the corresponding functions to which the hyper-elliptic or Abelian integrals are inverse, and how by means of them can Abel's theorem be stated?

Secondly, as in the same cases we obtain algebraical integrals of differential equations, whose variables are separated, but which nevertheless can only be directly integrated by means of transcendents*, what are the differential equations of which Abel's theorem gives us algebraical integrals? These two questions are, it is obvious, intimately connected.

M. Jacobi first takes the particular case in which the polynomial under the radical is of the fifth or sixth degree. If we call this polynomial X, it follows from Abel's theorem, that if

$$\varphi x = \int \frac{dx}{\sqrt{X}}$$

$$\text{and } \varphi_1 x = \int \frac{x\,dx}{\sqrt{X}},$$

we shall have the equations

$$\varphi a + \varphi b = \varphi x + \varphi y + \varphi x^1 + \varphi y^1,$$
$$\varphi_1 a + \varphi_1 b = \varphi_1 x + \varphi_1 y + \varphi_1 x^1 + \varphi_1 y^1,$$

where a and b are given as algebraical functions of the independent quantities x, y, x^1, y^1.

Let $\varphi x + \varphi y = u$ $\qquad$ $\varphi x^1 + \varphi y^1 = u^1$

$\varphi_1 x + \varphi_1 y = v$ $\qquad$ $\varphi_1 x^1 + \varphi_1 y^1 = v^1$.

* E.g. $\frac{dx}{\sqrt{1-x^2}} + \frac{dy}{\sqrt{1-y^2}} = 0$, of which the algebraical integral is $x\sqrt{1-y^2} + y\sqrt{1-x^2} = C$. Each term of this differential equation is a differential of a transcendent function $\sin^{-1}x$ or $\sin^{-1}y$.

Then x and y are both given as functions of u and v. We may therefore put

$$x = \lambda(uv), \qquad y = \lambda\ (uv);$$

and similarly,

$$x^1 = \lambda(u^1 v^1), \qquad y^1 = \lambda_1(u^1 v^1);$$

and as
$$\varphi a + \varphi b = u + u^1$$
$$\varphi_1 a + \varphi\ b = v + v^1,$$

we shall have
$$a = \lambda(u + u^1,\ v + v^1)$$
$$b = \lambda\ (u + u^1,\ v + v^1).$$

Hence the functions $\lambda\ (u + u^1,\ v + v^1)$ and $\lambda_1\ (u + u^1,\ v + v^1)$ are expressible as algebraical functions of $\lambda(uv)$, $\lambda_1\ (uv)$, $\lambda\ (u^1 v^1)$, $\lambda_1\ (u^1 v^1)$.

These then are functions to which the integrals are in a certain sense inverse, and which have the same fundamental property as circular and elliptic functions.

In the general case of Abel's theorem, we introduce (when the degree of the polynomial is $2m$ or $2m-1$), $m-1$ functions analogous to λ, each being a function of $m-1$ variables. These functions will, it may easily be shown, have the fundamental property just pointed out for the case in which m is equal to three.

Again, the differential equations of which Abel's theorem gives us algebraical integrals, are, if the degree of the polynomial X be five or six, the following:

$$\frac{dx}{\sqrt{X}} + \frac{dy}{\sqrt{Y}} + \frac{dz}{\sqrt{Z}} = 0,$$

$$\frac{x\,dx}{\sqrt{X}} + \frac{y\,dy}{\sqrt{Y}} + \frac{z\,dz}{\sqrt{Z}} = 0;$$

and generally, if the degree of the polynomial be $2m$ or $2m-1$, there are $m-1$ such equations, the numerators of the last containing the $(m-2)$th power of the variables.

M. Jacobi concludes by suggesting as a problem the direct integration of these differential equations, so as to obtain a proof of Abel's theorem corresponding to that which Lagrange gave of Euler's (vide *ante*, p. 36).

30. Another important paper by M. Jacobi is that which is entitled 'De Functionibus duarum Variabilium quadrupliciter periodicis, etc.' (Crelle, xiii. p. 55). It is here shown that a periodic function of one variable cannot have two distinct real periods. In the case of a circular function, though we have for all values of x

$$\sin x = \sin(x + 2m\pi)$$
$$= \sin(x + 2n\pi),$$

m and n being any integers, yet $2m\pi$ and $2n\pi$ do not constitute two *distinct* periods, since each is merely a multiple of 2π, which is the fundamental period of the function. But if we had for all the values of x

$$f(x) = f\{x + \alpha\} = f\{x + \beta\},$$

we should also have

$$f(x) = f(x + m\alpha + n\beta),$$

where m and n may be any integers, positive or negative. Hence $m\alpha + n\beta$

may, provided α and β are incommensurable, which is implied in their being distinct periods, be made less than any assignable quantity, so that we may put

$$fx = f(x + \varepsilon),$$

where ε is indefinitely small, and this manifestly is an inadmissible result. Accordingly we see that one at least of the periods of elliptic functions is necessarily imaginary.

Again, similar reasoning shows that in a triply periodic function, that is in one in which we have

$$f(x) = f\{x + m(\alpha + \beta\sqrt{-1}) + m'(\alpha' + \beta'\sqrt{-1}) + m''(\alpha'' + \beta''\sqrt{-1})\}$$

for every value of x, m, m', m'' being any integers, and in which the three periods $\alpha + \beta\sqrt{-1}$, &c. are *distinct*, we can make

$$f(x) = f(x + \varepsilon)$$

by assigning suitable values to m, m', m''; ε being as before less than any assignable quantity. Hence as this result is inadmissible, it follows that there is no such thing as a triply periodic function. Whenever therefore a function appears to have three periods they are in reality not distinct, and so *à fortiori* when it appears to have more than three. But now we come to a difficulty. For M. Jacobi proceeds to show that if we consider a function of one variable inverse to the Abelian integral $\int \frac{(\alpha + \beta x)\,dx}{\sqrt{X}}$, X being of the sixth degree in x, this function has four distinct and irreducible periods. His conclusion is that we cannot consider the amplitude of this integral as an analytical function of the integral itself. In the present state of our knowledge, this conclusion, though seemingly forced on us by the impossibility of recognising the existence of a quadruply periodic function of one variable, is not, I think, at all satisfactory. The functional dependence, the existence of which we are obliged to deny, may be expressed by a differential equation of the second order; and therefore it would seem that the commonly received opinion that every differential equation of two variables has a primitive, or expresses a functional relation between its variables, must be abandoned, unless some other mode of escaping from the difficulty is discovered. It is probable that some simple consideration, rather of a metaphysical than an analytical character, may hereafter enable us to form a consistent and satisfactory view of the question, and this I believe I may say is the opinion of M. Jacobi himself. The same difficulty meets us in all the Abelian integrals: as in the case of those of Legendre's first class, namely where X is of the fifth or sixth degree, so also generally, the inverse function has more than its due number of periodicities.

Abel, in a short paper in the second volume of his works, p. 51, has in effect proved the multiple periodicity of the functions which are inverse to the integrals to which his theorem relates. The difficulty to which this gives rise did not strike him, or was perhaps reserved for another occasion.

M. Jacobi next proves that his inverse functions of two variables are quadruply periodic, but that quadruple periodicity for functions of two variables is nowise inadmissible.

A difficulty however seems to present itself, which is suggested by M. Eisenstein in Crelle's Journal, viz. that if for each value of the amplitude the integral φx or $\int \frac{dx}{\sqrt{X}}$ (vide *supra*, p. 75), has an infinity of magnitudes real and imaginary, and the same is the case for φy, it is by no means easy

attach a definite sense to the equation $u = \phi x + \phi y$, or to see how the value of u is determined by it *.

31. Two divisions of the theory of the higher transcendents here suggest themselves, which are apparently less intimately connected than the corresponding divisions in the theory of elliptic functions, viz. the reduction and transformation of the integrals themselves, and the theory of the inverse functions.

But before considering these I shall give some account of what has been done in fulfilment of the suggestion made by M. Jacobi at the close of the 'Considerationes Generales.' Mathematicians have succeeded in effecting the integration of the system of differential equations to the consideration of which we are led by Abel's theorem, and which is commonly designated by German mathematicians as the "Jacobische system;" its existence and its integrability having been first pointed out by M. Jacobi.

In Crelle's Journal (xxiii. 354), M. Richelot, after modifying the form in which Lagrange's celebrated integration of the differential equation of elliptic integrals is generally presented, extended a similar method to the system of two differential equations which occurs when we consider the Abelian transcendents of the first class. He thus obtains one algebraical integral of the system. In the case of Lagrange's equation one integral is all we want; but in that which M. Richelot here discusses we require two. Now if in the former case we replace each of the variables by its reciprocal, we obtain a new differential equation of the same form as the original one, and integrable therefore in the same manner; and if in its integral we again replace each new variable by its reciprocal, that is by the original variable, we thus, as it is not difficult to see, get the integral of the original equation in a different form. That the two forms are in effect coincident may be verified *à posteriori*. But the same substitutions being made in M. Richelot's equations, which are of course those we have already mentioned at p. 76, the first of them becomes similar in form to the second, and *vice versâ* the second to the first. Thus the system remains similar to itself; and if in the algebraical integral we obtain of it we again replace the new variables by their reciprocals, we fall on a new algebraical integral of the original system; this integral being, which is remarkable, independent of that previously got. Thus the system of two equations is completely integrated. Extending his method to the general system of any number of equations, M. Richelot obtains for each two integrals, but of course these are not all that we want. At the conclusion of his memoir M. Richelot derives from Abel's theorem the algebraical integrals of the "Jacobische system."

Though in this memoir M. Richelot only obtained by direct integration two of the $m-1$ algebraical integrals of the "Jacobische system," yet he put the problem of its complete integration into a convenient and symmetrical form. As there are m variables and $m-1$ relations among them, we may suppose each to be a function of an independent variable t. Lagrange, as we know, in integrating the equation

$$\frac{dx}{\sqrt{X}} + \frac{dy}{\sqrt{Y}} = 0,$$

* The difficulty here mentioned may perhaps be met by saying that the value of ϕx determined by the integral $\int_0^x \frac{dx}{\sqrt{X}}$ is necessarily determinate, and so likewise is that of u. That considerations connected with the conception of a function inverse to ϕx make the latter quantity appear indeterminate is undoubtedly a difficulty; but it is, so to speak, a difficulty collateral to M. Jacobi's theory, and therefore need not prevent our accepting it.

introduced such an independent variable by the assumption $\frac{dx}{dt} = \sqrt{X}$, which of course implied that $\frac{dy}{dt} = -\sqrt{Y}$. This assumption is unsymmetrical, and it is therefore difficult to see how to generalise it. But if we assume $\frac{dx}{dt} = \frac{\sqrt{X}}{x-y}$, we shall of course have $\frac{dy}{dt} = \frac{\sqrt{Y}}{y-x}$, and therefore t is symmetrically related to x and y. Let $Fu = 0$ be an equation whose roots are x and y, then, as we know, when $u = x$, $F'u = x - y$ and, when $u = y$, $Fu = y - x$, so that using an abbreviated notation

$$\frac{dx}{dt} = \frac{\sqrt{X}}{F'(x)} \text{ and } \frac{dy}{dt} = \frac{\sqrt{Y}}{F'(y)}.$$

Nothing is easier than to generalise this result. For instance, the "Jacobische system" of two equations is

$$\frac{dx}{\sqrt{X}} + \frac{dy}{\sqrt{Y}} + \frac{dz}{\sqrt{Z}} = 0,$$

$$\frac{x\,dx}{\sqrt{X}} + \frac{y\,dy}{\sqrt{Y}} + \frac{z\,dz}{\sqrt{Z}} = 0.$$

Now if $Fu = 0$ have x, y, z for its roots, the two preceding equations may, in virtue of a very well-known theorem, be replaced by the three following,

$$\frac{dx}{dt} = \frac{\sqrt{X}}{F'x}, \quad \frac{dy}{dt} = \frac{\sqrt{Y}}{F'y}, \quad \frac{dz}{dt} = \frac{\sqrt{Z}}{F'z},$$

which introduce an independent variable t, symmetrically related to x, y and z; and so in all cases.

M. Richelot * then takes a symmetrical function of $x, y, \ldots z$, viz. their sum, and by means of the last written equations arrives at an integrable differential equation of the second order, the principal variable being the said

* As M. Richelot's method of demonstrating Euler's theorem is more symmetrical and far more easily remembered than Lagrange's, it ought, I think, to be introduced into all elementary works on elliptic functions. The equation to be integrated being

$$\frac{dx}{\sqrt{\alpha + \beta x + \gamma x^2 + \delta x^3 + \iota x^4}} + \frac{dy}{\sqrt{\alpha + \beta y + \gamma y^2 + \delta y^3 + \iota y^4}} = 0,$$

assume $$\frac{dx}{dt} = \frac{\sqrt{\alpha + \beta x + \gamma x^2 + \delta x^3 + \iota x^4}}{y - x}$$

Then $$\frac{dy}{dt} = \frac{\sqrt{\alpha + \beta y + \gamma y^2 + \delta y^3 + \iota y^4}}{x - y}.$$

Let $p = x + y$. Then after a few obvious reductions

$$\frac{d^2p}{dt^2} = \frac{1}{2}\delta + \iota p.$$

Hence $$\frac{dp^2}{dt^2} = \delta p + \iota p^2,$$

or $$\left\{\sqrt{\alpha + \beta x + \gamma x^2 + \delta x^3 + \iota x^4} - \sqrt{\alpha + \beta y + \gamma y^2 + \delta y^3 + \iota y^4}\right\}^2 = \delta(y - x)(y^2 - x^2) + \iota(y^2 - x^2)^2,$$

the algebraical integral sought. It may easily be expressed in other forms.

sum, and the independent variable being t. From the first integral of this equation it is easy to eliminate the differentials, and we have thus an algebraical relation in $x, y, \ldots z$, from which, in the manner already mentioned, M. Richelot deduces another. We now see that if we could find any other symmetrical function which would lead to an integrable equation we should get a finite relation among the variables.

In the next volume of Crelle's Journal M. Jacobi took the following function as his principal variable,

$$\surd\{(\mu - x)(\mu - y) \ldots (\mu - z)\},$$

μ being a root of $X = 0$ or $fx = 0$ if we suppose $X = fx$. Calling this function v, we get a simple differential equation in v and t, and a corresponding integral of the system. Now $fx = 0$ has $2m$ or $2m - 1$ roots, and we only want $m - 1$ integrals. The integrals therefore which we get by making μ the first, second, &c. root of $fx = 0$ are not all independent.

In the twenty-fifth volume of Crelle's Journal M. Richelot resumed the subject of his former paper, and discussed it in a very interesting memoir. This fundamental or principal result may be said to be a generalisation of M. Jacobi's. It is that in the function

$$\surd\{(\mu - x)(\mu - y) \ldots (\mu - z)\}$$

μ may have any value whatever. The resulting differential equation, though rather more complicated than when, with M. Jacobi, we suppose μ a root of $fx = 0$, is still very readily integrable. We have thus an indefinite number of algebraical integrals, since the quantity μ is arbitrary, but of course not more than $m - 1$ of them are independent.

In the same volume of Crelle's Journal, p. 178, there is a curious paper by Dr. Hœdenkamp, in which the algebraical integrals of Jacobi's system are for the case of a polynomial of the fifth degree under the radical deduced from geometrical considerations. It is shown that in a system of curvilinear coordinates (those of which MM. Lamé and Liouville have made so much use), the equations of the system are the differential equations given by the Calculus of Variations for the shortest line between two points. Consequently the finite equations of a straight line are the integrals sought. This very ingenious consideration is afterwards generalised.

32. In the twelfth volume of Crelle's Journal, p. 181, M. Richelot has considered the Abelian integral of the first class. The principal result at which he arrives is, that the only rational transformation by means of which such an integral may be changed into one of similar form is linear in both the variables which it involves. By means of this substitution, he transforms, under certain conditions, the integral in question into a form analogous to the standard forms of elliptic integrals. The subject of the division of hyperelliptic integrals of each class into three genera is also considered, and the same principle of classification as Legendre's is made use of. The paper concludes by pointing out an error which Legendre committed in the application of his principle. Legendre had thought that the formula of summation given by Abel's theorem for integrals of the form $\int \frac{x^e\,dx}{\surd \varphi x}$ could not involve a logarithmic function. Thus these integrals would belong to the first or second kind, according to the value of the index e, and of λ the degree of φx. But in reality, though the integrals in question are of the first kind (that is, they admit of summation without introducing either an algebraical or logarithmic function) if e be less than a certain limit, yet if it be not so their formula of summation will in general involve both algebraical and loga-

rithmic functions. Either may, under certain conditions as to the form of ϕx, disappear, but while ϕx is merely known as the polynomial of the λth degree, we cannot decide whether the integral is to be referred to the second or third kind.

I may mention here a very elegant result due to M. Jacobi. It appears in the thirtieth volume of Crelle's Journal, p. 121, and is a generalisation of the fundamental formula for the addition of elliptic arcs. With a slight modification it may be thus stated. If ϕx involve only even powers of x, the highest being x^{4m}, then the sum of the integrals $\int_0^x \frac{x^{2m} dx}{\sqrt{\phi(x)}}$ is equal to the product of their arguments, that is of the different quantities denoted by the symbol x. In this case then the logarithmic function disappears, and the integral belongs to the second kind.

In the twenty-ninth volume of Crelle's Journal there is a paper by M. Richelot on a question connected with hyper-elliptic integrals. The reader will find in it a good many fully-developed results, which may be considered as particular cases of Abel's theorem. They illustrate the learned author's criticism of Legendre's classification of hyper-elliptic integrals, though they are not adduced for that purpose.

The function M (vide *ante*, p. 38) is a function of the arbitrary quantities $a, b, \ldots c$, which, as has been remarked, may themselves be considered functions of the arguments $x_1, x_2, \ldots x_\mu$. To determine M as a function of the last-written quantities is a necessary ulterior step in almost any special application of Abel's theorem, and this M. Richelot has done in several interesting cases, establishing at the same time the relations which exist among the quantities in question. His investigations, however, have an ulterior purpose, and are not to be considered merely as corollaries from Abel's theorem.

Another paper of M. Richelot, on the subject of the Abelian integrals, is found in the sixteenth volume of Crelle's Journal, p. 221. The aim of it is to furnish the means of actually calculating the value of the Abelian integral of the first class by a method of successive transformation, that is, by a method analogous to that used for elliptic integrals. M. Richelot's process depends essentially on an irrational substitution, by means of which we can replace the proposed integrals by two others which differ only with respect to their limits. In the development of this idea the author confines himself to the first kind of the Abelian integrals of the first class, though the same method may *m . m .* be more generally applied *. From the formula which expresses the proposed integral as the aggregate of two others is deduced another, in which it is expressed by means of four integrals, the inferior limits of all being zero. The first and second of these integrals differ only in their amplitude, and the same is true of the third and fourth. There are two principal transformations, either of which may be repeated as often as we please; and though it might seem that the number of integrals would in the successive transformations increase in a geometrical progression, yet by the application of Abel's theorem we can always reduce them to the same number. But the development of this part of the subject M. Richelot has reserved for another occasion †.

* The integral to be transformed is $\frac{\{M+Nz\}dz}{\sqrt{\{z(1-z)(1-k^2z)(1-\lambda^2z)(1-\mu^2z)\}}}$, M and N, &c. being constant.

† His transformations ultimately reduce the hyper-elliptic integral to elliptic integrals; the latter may be considered known quantities, "vel per paucas adjectas transformationes directe computentur."

At the close of his memoir, M. Richelot has given some numerical examples of his method for the case of a complete hyper-elliptic integral. The third example he had previously given in a brief notice of his researches, published in No. 311 of Schumacher's Journal.

33. For many years after the death of Legendre the subject of the comparison of transcendents was studied principally by German and Scandinavian writers*: a young French mathematician, M. Hermite, has recently made important discoveries in this theory; but as the principal part of what he has done is as yet not published, a very imperfect outline is all that can be given.

In the seventeenth volume of the 'Comptes Rendus' we find the report of a commission, consisting of MM. Lamè and Liouville, on a memoir presented to the Institute by M. Hermite. This report is reprinted in the eighth volume of Liouville's Journal, p. 502. A remark which incidentally occurs in it, namely, that Abel was the first to give the general theory of the division of elliptic integrals, led to a very warm discussion between MM. Liouville and Libri, on the subject of the claims which, as I have already remarked, the latter had made with reference to this theory.

It appears from the report, that M. Hermite has succeeded in solving the problem of the division of hyper-elliptic integrals. The division of elliptic integrals depends on the solution of an algebraical equation; that of the hyper-elliptic integrals (as the functions inverse to them involve, as we have seen, more than one variable), on the solution of a system of simultaneous algebraical equations. This solution can, M. Hermite has shown, be effected by means of radicals asuming, as in the analogous case of elliptic functions, the division of the complete integrals. M. Hermite's method depends for the most part on the periodicity of the functions considered. A transcendental expression of the roots of the equation of the problem having been obtained, their algebraical values are deduced from it.

These researches, in themselves of great interest, are yet more interesting, when we consider how completely they justify the views of M. Jacobi as to the manner in which Abel's theorem ought to be interpreted, by showing that his theory of the higher transcendents is no barren or artificial generalisation.

At page 505 of the volume of Liouville's Journal already mentioned, we find an extract from a letter of M. Jacobi to M. Hermite, in which, after congratulating him on the important discovery he had made, he points out that the transcendental functions $\lambda(u\,v)$, $\lambda_1(u\,v)$ (vide *ante*, p. 76) are algebraical functions of transcendental functions which involve but one variable.

M. Hermite's subsequent researches have embraced a much more general theory than that of the Abelian integrals, namely, that of the integrals of any algebraical function whatever. Thus his views bear the same relation to Abel's general theory, developed in the 'Savans Etrangers,' that those of M. Jacobi in the 'Considerationes Generales' do to Abel's theorem.

All that has yet been published with respect to them is contained in the 'Comptes Rendus,' xviii. p. 1133, in the form of an extract of a letter from M. Hermite to M. Liouville. This extract is reprinted in Liouville's Journal ix. p. 353. It was communicated to the Institute in June 1844.

Following the course of M. Jacobi's inquiries, M. Hermite proposed to determine what are the differential equations of which Abel's investigation give the complete algebraical integrals. When this is done it suggests th

* The papers of M. Liouville, already noticed, may be said to be an exception to th remark.

nature of the inverse functions which are to be introduced. The number of these functions will of course vary in different cases, just as in M. Jacobi's less general theory. Let us suppose this number to be denoted by γ, then each function will involve γ variables. And if each of these variables be replaced by the sum of two new variables, then all the functions are given as the roots of an equation of the γth degree, whose coefficients are rational in terms of the corresponding functions of each of the new variables and of certain known algebraical functions. From hence is derived the theory of the periodicity of these functions.

After some other remarks on the theory of the higher transcendents, M. Hermite states that the method of division of which he made use in the problem of the division of Abelian integrals extends also to the new transcendents now considered, but that in the theory of transformation he had not as yet been successful. The greater part of the remainder of this remarkable communication relates to elliptic functions, and has been already noticed. The remark just mentioned as having been made by M. Jacobi for the functions which are inverse to the Abelian integrals, extends, M. Hermite observes, to the functions which he considers.

In conclusion, M. Hermite remarks that the method of differentiation with respect to the modulus of which Legendre made so much use in the theory of elliptic functions, may be applied to all functions of the form

$$\int f(xy)\,dx,$$

where y is given by the equation

$$y^n - X = 0.$$

In concluding this report, it may be remarked that the subject of it is still incomplete, and that there is yet much to be done which we may hope it will not be found impossible to do. It is however difficult to predict the direction in which progress will hereafter be made. Yet I think we may reasonably suppose that the question of multiple periodicity, from the paradoxical aspect in which it has presented itself, and from its connexion with the general principles of the science of symbols, will sooner or later attract the attention of all philosophical analysts. M. Liouville's idea of considering the conditions to which a doubly periodic function must as such be subject, can scarcely be developed or extended to the higher transcendents without leading to results of great generality and interest.

The detailed discussion of different classes of algebraical integrals, their transformations and reductions, form an endless subject of inquiry. But in this, as in other cases, the increasing extent of our knowledge will of itself tend to diminish the interest attached to the full development of particular portions of it; and with reference to analytical problems arising out of questions of physical science, the theory of the higher transcendents will it is probable never become of so much importance as the theory of elliptic functions. We have occasion to make use of circular much more frequently than of elliptic functions, and similarly we shall, it may be presumed, have less frequently to introduce the higher transcendents than elliptic functions. Numerical calculations of the values of the higher transcendents are therefore less important than similar calculations in the case of elliptic functions*.

* The Academy of Sciences has proposed as the subject of the great mathematical prize for 1846 the following question:—"Perfectionner dans quelque point essentiel la théorie des fonctions abéliennes ou plus généralement des transcendantes qui résultent de la considération des intégrales de quantités algébriques." The memoirs are to be sent in before the 1st of October.

The following index is intended to contain references to all the papers in the first thirty-one volumes of Crelle's Journal, and in the first ten volumes of Liouville's Journal, more or less connected with the subject of this report, together with a considerable number of others.

In the following Index Crelle's Journal is denoted by C., *Liouville's by* L., *and the present Report by* R.

Abel. Ueber die Integration der differential Formel $\frac{\rho dx}{\sqrt{R}}$ wenn R and ρ ganze Functionen sind.—C. i. 185. This paper contains formulæ of reduction. It is mentioned by M. Liouville, 'Journal de l'Ecole Polytechnique,' 23d cah. p. 38. It appears in French in Abel's collected works, tom. i. 33.

——. Recherches sur les Fonctions Elliptiques.—C. ii. 101, and iii. 160 [1827]. V. Abel's works, i. 141; also R. p. 57.

——. Remarques sur quelques Propriétés Générales d'une certaine sorte de Fonctions Transcendantes.—C. iii. 313. This paper contains the theorem commonly known as 'Abel's Theorem.' V. Abel's works, i. 288; also R. p. 40.

——. Sur le Nombre de Transformations Différentes qu'on peut faire subir à une Fonction Elliptique par la Substitution d'une Fonction donnée du premier dessé.—C. iii. 394. V. Abel's works, i. 309.

——. Théorème Général sur la Transformation des Fonctions Elliptiques de la seconde et de la troisième espèce.—C. iii. 402. The theorem is stated without demonstration. V. Abel's works, i. 317.

——. Note sur quelques Formules Elliptiques.—C. iv. 85. This paper contains developments of elliptic functions, &c. V. Abel's works, i. 299.

——. Théorèmes sùr les Fonctions Elliptiques.—C. iv. 194. They relate to the demonstration of the theorem stated by M. Jacobi in the third volume of Crelle's Journal, p. 86, by means of which Abel's method for the division of elliptic integrals is greatly simplified. V. Abel's works, i. 318; also R. p. 59.

——. Démonstration d'une Propriété Générale d'une certaine Classe de Fonctions Transcendantes.—C. iv. 200. This short paper contains the fundamental idea of the memoir presented to the Institute in 1826. V. Abel's works, i. 324; also R. p. 40.

——. Précis d'une Théorie des Fonctions Elliptiques.—C. iv. 236 and 309. This *précis* was left unfinished. V. Abel's works, i. 326; also R. p. 65.

——. Extracts from Letters to M. Crelle, one of which relates to the comparison of Transcendents.—C. v. 336. V. Abel's works, ii. 253.

——. A Letter to M. Legendre.—C. vi. 73. Works, ii. 256. It contains a theorem proved by M. Ramus in the twenty-fourth volume of Crelle's Journal, p. 78; and another, proved by M. Liouville in the twenty-third cahier of the 'Journal de l'Ecole Polytechnique.' V. R. p. 41 and p. 70.

——. Mémoire sur une certaine classe de Fonctions Transcendantes. Presented to the Institute, Oct. 30, 1826, published in 1841 in the 'Mémoires des Savans Etrangers,' vii. 176. It is the only memoir of Abel's not contained in the collected edition of his works published in 1839; the editor, M. Holmboe, not having been able to procure a copy of it. V. R. p. 39.

——. Solution d'un Problème Général concernant la Transformation des Fonctions Elliptiques.—Schumacher's Astronomische Nachrichten, No. 138, vi. 365. V. Abel's works, i. 253; also R. p. 62.

ABEL. Addition au Mémoire Précédent.—Schumacher's Astronomische Nach. No. 147, vii. 33. V. Abel's works, i. 275; also R. *ubi supra.* The following papers were published for the first time in Abel's collected works. The references are to the second volume:—

—. Propriétés remarquables de la Fonction $y=\varphi x$, etc., p. 51. The multiple periodicity of a function inverse to a hyper-elliptic integral is here mentioned. V. R. p. 77.

—. Sur une Propriété remarquable d'une Classe très étendue de Fonctions Transcendantes, p. 54. This paper contains a generalisation of a theorem relating to elliptic functions.

—. Extension de la Théorie Précédente, p. 58.

—. Sur la Comparaison des Fonctions Transcendantes, p. 66. This paper contains a somewhat fuller development of his general theory than that which is inserted in the fourth volume of Crelle's Journal, p. 200. V. R. p. 40.

—. Théorie des Transcendantes Elliptiques, p. 93. V. R. p. 66.

—. Démonstration de quelques Formules Elliptiques, p. 210.

BROCH. Sur quelques Propriétés d'une certaine classe des Fonctions Transcendantes.—C. xx. 178. An extension of Abel's theorem. V. R. p. 40.

—. Mémoire sur les Fonctions de la forme

$$\int x^{s-\gamma p-1} \mathrm{F}(x^p)\,(\mathrm{R}(x^p))^{\pm\frac{s}{\gamma p}}\,dx, \text{ etc.}—\text{C. xxiii. 145 and 201.}$$

This memoir, of which the first part may be considered a generalisation of the preceding, is accompanied by a report of MM. Liouville and Cauchy. V. R. p. 41.

BRONWIN. On Elliptic Functions.—Camb. Mathematical Journal, iii. 123. Mr. Bronwin puts the transcendental formula of transformation in a very neat form.

—. On M. Jacobi's Theory of Elliptic Functions.—Lond., Ed. and Dub. Phil. Mag. xxii. 258. V. R. p. 53.

—. Reply to Mr. Cayley's Remarks.—L., E. & D. Phil. Mag. xxiii. 89. V. R. *ubi supra.*

CATALAN. Sur la Réduction d'une Classe d'Intégrales Multiples.—L. iv. 323.

—. Sur les Transformations des Variables dans les Intégrales Multiples. Mémoires Couronnés par l'Académie Royale de Bruxelles, xiv. 2de partie, p. 1. The third part contains a transformation of a multiple integral leading to properties of hyper-elliptic integrals analogous to known properties of elliptic integrals.

CAUCHY. Comptes Rendus, xvii. 825.—V. R. p. 69.

CAYLEY. Mémoire sur les Fonctions doublement Périodiques.—L. x. 385. An enlargement of his paper on the inverse elliptic functions, published in the fourth volume of the Cambridge Mathematical Journal. V. R. p. 69.

—. Remarks on the Rev. B. Bronwin's paper.—L., E. and D. Phil. Mag. xxii. 358.

—. Investigation of the Transformation of certain Elliptic Functions.—L., E. and D. Phil. Mag. xxv. 352. V. R. p. 69.

—. On the Inverse Elliptic Functions.—Camb. Math. Journal, iv. 257. V. R. p. 69.

CHASLES. Comptes Rendus de l'Institut, xvii. 838, and xix. 1239. M. Chasles in these two communications presents to the Institute notices of his geometrical researches illustrative of the theory of elliptic functions. V. R. p. 74.

CLAUSEN. Schumacher's Nachrichten, xix. 178. On a particular Integral mentioned by Legendre.

——. Schumacher's Nachrichten, xix. 181. It is shown that the arcs of one of the curves, known as the Spirica of Perseus, may be rectified by means of an elliptic integral.

EISENSTEIN. Théorèmes sur les Formes Cubiques.—C. xxvii. 75. At the end of this paper we find some developments of elliptic functions in continued fractions. This subject is continued in the following paper of M. Eisenstein's.

——. Transformations remarquables de quelque Séries.—C. xxvii. 193. and xxviii. 36. See also Theorema, C. xxix. 96.

——. Bemerkungen zu den elliptischen und Abelschen Transcendenten.—C. xxvii. 185. M. Jacobi has criticised this paper (of which a translation appears in Liouville's Journal, x. 445) in the thirtieth volume of Crelle's Journal.

——. Elementare Ableitung einer merkwürdiger Relation zwischen zwei unendlichen Producten.—C. xxvii. 285. V. R. p. 70.

——. Beitrage zur Theorie der Elliptischen Functionen.—C. xxx. 185, 211. This paper contains a demonstration of the fundamental formula of elliptic functions. V. R. p. 71.

GUDERMANN. Integralia Elliptica Tertiæ Speciei Reducendi Methodus Simplicior, &c.—C. xiv. 159, 185. V. R. p. 68.

——. Einige Bemerkungen über Elliptische Functionen.—C. xvi. 78.

——. Series novæ quarum ope Integralia Elliptica Primæ et Secundæ Speciei computantur, &c.—C. xvi. 366. and xvii. 382.

——. Theorie der Modular Functionen und der Modular Integrale.—C. xviii. 1, 142, 220, 303; xix. 46, 119, 244; xx. 62, 103; xxi. 240; xxiii. 301; xxv. 281. A systematic treatise on elliptic functions. V. R. p. 69.

GÖTZLAFF. Æquatio Modularis pro Transformatione Functionum Ellipticarum Septimi Ordinis.—C. xii. 173. V. R. p. 68.

HAEDENKAMP. De Transformatione Integralis $\int\int \frac{d\varphi\, d\psi}{\sqrt{(\sin^2 v - \sin^2\varphi \cos^2\psi)}}$.—C. xx. 97. It is shown to be the product of two elliptic integrals.

——. Über Transformation vielfacher Integrale.—C. xxii. 184. Analogous to the researches of M. Catalan in the 'Mémoires de Bruxelles,' which appears to have been previously published.

——. Über Abelsche Integrale.—C. xxv. 178. V. R. p. 80.

HERMITE. Sur la Théorie des Transcendantes à Différentielles Algébriques.—L. ix. 353. Extracted from the 'Comptes Rendus' [June 1844]. This note, which contains scarcely more than an indication of M. Hermite's results, may be said to mark the furthest advance yet made in the theory of the comparison of transcendents. V. R. p. 82.

HILL. Exemplum usus Functionum Iteratarum, &c.—C. xi. 193. This paper contains some interesting applications of the calculus of functions to the comparison of transcendents. V. R. p. 42.

JACOBI. Addition au Mémoire de M. Abel sur les Fonctions Elliptiques.—C. iii. 86. A short note, containing an important simplification of Abel's method of solving the equation of the problem of division. V. R. p. 59.

——. Note sur la Décomposition d'un Nombre donné en quatre quarrés.—C. iii. 191. The demonstration referred to is founded on elliptic functions.

Note sur les Fonctions Elliptiques.—C. iii. 192.

JACOBI. Suite des Notices sur les Fonctions Elliptiques.—C. iii. 303.

——. Suite des Notices, &c.—C. iii. 403.

——. Suite des Notices, etc.—C. iv. 185. These notes contain theorems stated for the most part without demonstration. V. R. p. 56.

——. Ueber die Anwendung der elliptischen Transcendenten auf ein bekanntes Problem der Elementar-geometric, u. s. w.—C. iii. 376. This paper contains a geometrical construction for the addition and multiplication of elliptic integrals of the first kind. A translation of the most important part appears in Liouville's Journal, x. 435. V. R. p. 73.

——. De Functionibus Ellipticis Commentatio.—C. iv. 371. Transformations of integrals of the second and third kinds, &c. V. R. p. 66.

——. De Functionibus Ellipticis Commentatio altera.—C. vi. 397. We find here an elementary demonstration of M. Jacobi's theorem. V. R. p. 66.

——. Note sur une nouvelle application de l'Analyse des Fonctions Elliptiques à l'Algèbre.—C. vii. 41. It relates to the development in continued fractions of a function of the fourth degree.

——. Notiz zu Théorie des Fonctions Elliptiques de Legendre, Troisième Supplément.—C. viii. 413. V. R. p. 67.

——. De Theoremate Abeliano—C. ix. 99. V. R. p. 41.

——. Considerationes Generales de Transcendentibus Abelianis.—C. ix. 394 [1832]. This memoir lays the foundation of the theory of the higher transcendents. V. R. p. 75.

——. De Functionibus Duarum Variabilium quadrupliciter Periodicis, &c. —C. xiii. 55. M. Jacobi here proves the impossibility of a function of one variable being triply periodic. V. R. p. 76.

——. De usu Theoriæ Integralium Ellipticorum et Integralium Abelianorum in Analysi Diophanteâ.—C. xiii. 353. It is here pointed out that a problem of indeterminate analysis, discussed by Euler in the posthumous memoirs recently published by the Academy of St. Petersburg, is in effect that of the multiplication and addition of elliptic integrals. Suggestions are made as to the corresponding application that might be made of the Abelian integrals.

——. Formulæ novæ in Theoriâ Transcendentium Fundamentales.—C. xv. 199. Elegant elementary formulæ.

——. Note von der Geodätischen Linie auf einem Ellipsoid, u. s. w.—C. xix. 309. M. Jacobi has here announced the important discovery that the equation to the shortest line on an ellipsoid is expressible by means of Abelian integrals of the first class. As this is perhaps the first application made of Abelian integrals since their recognition as elements of analysis, I have thought it well to mention it in this place. A translation of the note is found in Liouville's Journal, vi. 267.

——. Demonstratio nova Theorematis Abeliani.—C. xxiv. 28. V. R. p. 80.

——. Zur Theorie der elliptischen Functionen.—C. xxvi. 93. This paper contains series for the calculation of elliptic functions, and a table of the function q.

——. Ueber die Additions-theoreme der Abelschen Integrale zweiter und dritter Gattung.—C. xxx. 121. We find here some remarkable formulæ. V. R. p. 81.

——. Note sur les Fonctions Abéliennes.—C. xxx. 183. This note relates principally to the fact announced in M. Jacobi's letter to M. Herm[illegible] V. L. viii. 505.

JACOBI. Ueber einige die Elliptischen Functionen betreffenden Formeln.—C. xxx. 269.

——. Extrait d'une Lettre à M. Hermite.—L. viii. 505. V. R. p. 82.

——. Extraits de deux Lettres de M. Jacobi, &c.—Schumacher's Nachrichten, vi. 33 [Sept. 1827]. They contain the first announcement of his theorem.

——. Demonstratio Theorematis ad Theoriam Functionum Ellipticarum Spectantis.—Schumacher, vi. 133. The first published demonstration of his theorem. See also Legendre at p. 201 of the same volume. V. R. pp. 47 and 48.

JÜRGENSEN. Sur la Sommation des Transcendantes à Différentielles Algébriques.—C. xix. 113.

——. Remarques Générales sur les Transcendantes à Différentielles Algébriques.—C. xxiii. 126. V. R. p. 41.

IVORY. On the Theory of the Elliptic Transcendents.—Phil. Trans., 1831, p. 349. V. R. p. 67.

LIBRI. Sur la Théorie des Nombres.—Mémoires des Savans Etrangers, v. 1.

——. Sur la Résolution des Equations Algébriques, &c.—C. x. 167. These memoirs are referred to in the controversy between MM. Liouville and Libri.

LIOUVILLE. Sur les Intégrales de Valeur Algébrique.—Journal de l'Ecole Polytechnique, cah. xxii. 124 and 149. These two memoirs are printed also in the fifth volume of the 'Mémoires des Savans Etrangers,' pp. 76, 105. Poisson's report on them is inserted in the tenth volume of Crelle's Journal, v. *infra*.

——. Sur les Transcendantes Elliptiques de Première et de Seconde Espèce.—Journ. de l'Ecole Polytech., cah. xxiii. 37. V. R. p. 70.

——. Note sur la Détermination des Intégrales dont la Valeur est Algébrique.—C. x. 347. This note is appended to Poisson's report.

——. Sur l'Intégration d'une Classe de Fonctions Transcendantes.—C. xiii. 93. On the same general subject as the preceding memoirs.

——. Sur la Classification des Transcendantes.—L. ii. 56, and iii. 523. These papers contain an exposition of the principles on which this classification is to be effected.

——. Sur les Transcendantes Elliptiques de Première et de Seconde Espèce considérées comme Fonctions de leurs Modules.—L. v. 34 and 441. It is proved that these transcendents so considered cannot be reduced to algebraical functions.

——. Rapport fait à l'Académie des Sciences, &c.—L. viii. 502. Report on M. Hermite's memoir. V. R. p. 82.

——. Sur la Division du Périmètre de la Lemniscate.—L. viii. 507. V. R. p. 62.

——. Rapport sur le Mémoire de M. Serret sur la Représentation Géometrique des Fonctions Elliptiques et Ultra-elliptiques.—L. x. 290. A note is appended to this report generalising M. Serret's theory. V. R. p. 72.

——. Sur un Mémoire de M. Serret, &c.—L. x. 456. V. R. p. 73.

LOBATTO. Sur l'Intégration de la Différentielle $\frac{dx}{\sqrt{x^4+\alpha x^3+\beta x^2+\gamma x+\delta}}$.—C. x. 280.

LUCHTERHANDT. De Transformatione Expressionis

$$\frac{dy}{\sqrt{[\pm(y-\alpha)(y\quad\beta)(y-\delta)]}},\ \&c.$$

—C. xvii. 248.

MacCullagh. Transactions of the Royal Irish Academy, xvi. 76. An elegant geometrical proof of Landen's theorem.

Minding. Théorème relatif à une certaine Fonction Transcendante.—C. ix. 295. The function in question was shown by M. Richelot to be reducible to elliptic integrals.

——. Sur les Intégrales de la forme $\int \frac{dx P\sqrt{p}}{c-x}$, &c.—C. x. 195. An addition to this memoir is found at p. 292 of the same volume.

——. Recherches sur la Sommation d'un certain nombre de Fonctions Transcendantes, &c.—C. xi. 373. These researches relate to an extension of Abel's theorem.

——. Propositiones quædam de Integralibus Functionum Algebraicarum unius variabilis e principiis Abelianis derivatæ.—C. xxiii. 255. This memoir is mentioned by M. Hermite.

Poisson. Rapport sur deux Mémoires de M. J. Liouville, &c.—C. x. 342. V. *supra, Liouville.*

——. Théorèmes relatifs aux Intégrales des Fonctions Algébriques.—C. xii. 89. V. R. p. 41.

Raabe. Bemerkungen zum Principe der doppelten Substitution, u. s. w.—C. xv. 191.

Ramus. De Integralibus Differentialium Algebraicarum.—C. xxiv. 69. V. R. p. 41.

Richelot. Note sur le Théorème, &c.—C. ix. 407. V. *supra, Minding.*

——. De Integralibus Abelianis Primi Ordinis Commentatio Prima.—C. xii. 181. V. R. p. 80.

——. De Transformatione Integralium Abelianorum Primi Ordinis Commentatio.—C. xvi. 221 and 285. V. R. p. 81.

——. Ueber die Integration eines merkwürdigen Systems Differentialgleichungen.—C. xxiii. 354. These equations are those known as the "Jacobische System." V. R. p. 78.

——. Einige neue Integral-gleichungen des Jacobischen Systems Differential-gleichungen.—C. xxv. 97. The results contained in this paper are much more general than those of the preceding one. V. R. p. 80.

——. Nova Theoremata de Functionum Abelianorum cujusque ordinis Valoribus, &c.—C. xxix. 281. V. R. p. 81.

——. Ueber die auf wiederholten Transformationen beruhende Berechnung der ultra-elliptischen Transcendenten.—Schumacher Astr. Nach. xiii. 361 [July, 1836]. V. R. p. 82.

Roberts. Sur une Représentation Géométrique des Fonctions Elliptiques de Première Espèce.—L. viii. 263.

——. Sur une Représentation Géométrique des Trois Fonctions Elliptiques.—L. ix. 155. Mr. Roberts's papers relate to curves formed by the intersection of a cone of the second order with a sphere. The following paper contains a more general exposition of his views.

——. Mémoire sur quelques Propriétés Géométriques relatives aux Fonctions Elliptiques.—L. x. 297. V. R. p. 73.

Rosenhain. Exercitationes Analyticæ in Theorema Abelianum de Integralibus Functionum Algebraicarum.—C. xxviii. 249, and xxix. 1. V. R. p. 41.

Sanio. De Functionum Ellipticarum Multiplicatione et Transformatione quæ ad numerum parem pertinet Commentatio.—C. xiv. 1. V. R. p. 68.

Serret. Note sur les Fonctions Elliptiques de Première Espèce.—L. viii. 145. V. R. p. 72.

SERRET. Propriétés Géométriques relatives à la Théorie des Fonctions Elliptiques.—L. viii. 495.

——. Note à l'occasion du Mémoire de M. William Roberts, &c.—L. ix. 160.

——. Mémoire sur la Représentation Géométrique des Fonctions Elliptiques et Ultra-elliptiques. Addition au mémoire précédent.—L. x. 257 and 286. It was on this memoir that M. Liouville made so favourable a report to the Institute. V. R. p. 72.

——. Développemens sur une Classe d'Équations relatives a la Représentation des Fonctions Elliptiques.—L. x. 351.

——. Note sur les Courbes Elliptiques de la Première Classe.—L. x. 421.

——. Sur la Représentation des Fonctions Elliptiques de Première Espèce.—Camb. and Dublin Math. Journ. i. p. 187.

SOHNCKE. Æquationes Modulares pro Transformatione Functionum Ellipticarum et undecimi et decimi tertii et decimi septimi ordinis.—C. xii. 178. M. Sohncke here gives the results which he investigates by a general method in the following paper.

——. Æquationes Modulares, &c.—C. xvi. 97. V. R. p. 68.

TALBOT. Researches in the Integral Calculus.—Phil. Trans. 1836, p. 177; 1837, p. 1. V. R. p. 41.

On Comparative Analytical Researches on Sea Water.
By Prof. FORCHHAMMER.

IN a paper read today in the Chemical Section, I have tried to show that in the ocean between Europe and America, the greatest quantity of saline matter is found in the tropical region far from any land; in such places 1000 parts of sea water contain 36·6 parts of salt. This quantity diminishes in approaching the coast, on account of the masses of fresh water which the rivers throw into the sea; it diminishes likewise in the westernmost part of the Gulf-stream, where I only found it to be 35·9 in 1000 parts of the water. By the evaporation of the water of this warm current, its quantity of saline matter increases towards the east, and reaches in N. lat. 39° 39′ and W. long. 55° 16′, its former height of 36·5. From thence it decreases slowly towards the north-east, and sea water, at a distance of sixty to eighty miles from the western shores of England, contains only 35·7 parts of solid substances; and the same quantity of salt is found all over the north-eastern part of the Atlantic as far to the north as Iceland, always at such a distance from the land that the influence of fresh water from the land is avoided. From numerous observations made on the shores of Iceland and the Faröe islands, it is evident that the water of the Gulf-stream spreads over this part of the Atlantic Ocean, and thus we see that water of tropical currents will keep its character even in high northern latitudes.

Besides the southerly direction which any current flowing from the northern polar regions must take, it will, according to well-known physical laws depending upon the rotation of the earth, always take a direction towards the west, and thus be driven towards the eastern shores of the continents, while any tropical current flowing towards the north will, according to the same law of rotation, take a direction towards the western shores of the continents. This is at present the case in the Atlantic Ocean, and its effects upon the shores of Europe, which by a branch of a tropical current are surrounded by warm water, produce a mild and moist climate.

The water of the different seas is much more uniform in its composition than is generally believed. In that respect my analyses agree with the newer analyses of atmospheric air, in showing that the differences are very slight indeed. Sea water may contain more or less salt, from a very small quantity, as in the interior part of the Baltic, to an amount of 37·1 parts in 1000 parts, which I found in water from Malta, and which is the greatest quantity I ever observed; but the relative proportion of its constituent saline parts changes very little.

In order to get rid of those differences which might arise from the different quantity of saline matter in sea water, I have compared sulphuric acid and lime with chlorine, and the following results are the mean of many analyses:—

In the *Atlantic*, the proportion between *chlorine* and *sulphuric* acid is 10,000 : 1188; this is the mean of twenty analyses, which differ very little from each other.

In the sea between the Faröe islands, Iceland and Greenland, the same proportion, according to the mean of seventeen analyses, is 10,000 : 1193.

In the German Ocean, according to ten analyses, it is 10,000 : 1191.

In Davis's Straits, according to the mean of five analyses, it is 10,000 : 1220.

In the Kattegat, according to the mean of four analyses, it is 10,000 : 1240.

Thus it appears that the proportion of sulphuric acid increases near the shores, a fact which evidently depends upon the rivers carrying sulphate of lime into the sea.

The proportion between *chlorine* and *lime* in the Atlantic Ocean, according to the mean result of seventeen analyses, is 10,000 : 297; and in the sea between Faröe and Greenland, according to the mean of eighteen analyses, it is 10,000 : 300.

In the longitude of Greenland, and more than 100 miles to the south of the southernmost point of that large tract of land, sea water contains only 35·0 in 1000 parts. In going from this point towards the north-west it decreases constantly, and in Davis's Straits, at a distance of about forty miles from the land, it only contains 32·5 parts of salt in 1000 parts of sea water. This character seems to remain in the current which runs parallel to the shores of North America; and at N. lat. 43½° and W. long. 46⅓ the sea water contained only 33·8 parts of salt. Thus tropical and polar currents seem not only to be different in respect to their temperature, but also in the quantity of salt which they contain; from which it appears, that while the quantity of water carried away from the *tropical sea* by evaporation is greater than that which rain and the rivers give back to that sea, the reverse takes place in the *polar seas*, where evaporation is very small and the condensation of vapour very great. The circulation must on that account be such, that a part of the vapour which rises in tropical zones will be condensed in polar regions, and in the form of polar currents flow back again to warmer climates. Although my analyses are only made on water from the ocean between Europe and America, yet little doubt can be entertained that that part of the ocean which separates America from Asia is constituted in a similar manner, and that currents flowing from the poles are the rule, and currents flowing towards the poles the exception.

Lime is rather rare in the sea around the West Indian islands, where millions of coralline animals constantly absorb it, the proportion according to five analyses being 10,000 : 247; and it is rather copious in the Kattegat, where the numerous rivers of the Baltic carry a great quantity of it into the ocean. The proportion is there, according to four analyses, 10,000 : 371.

On the Calculation of the Gaussian Constants for 1829. *By* A. Erman.

As purely theoretical speculations on natural phænomena remain highly unsatisfactory until they can be founded on a sufficient number of observations, in the same manner collections of the most careful observations must be almost useless before they are thoroughly elaborated according to a given theory. Nay, the accumulation of observed numbers, notwithstanding the value they possess when viewed by themselves, may even become injurious to science, by retarding its progress. Indeed the aspect of progressively increasing, but not duly elaborated, materials, must at last give rise to the apprehension, both on the part of those engaged in furnishing them, and of every one interested in the results to be gathered from them, that the means may be wanting to bring such a stock of matter to bear for their proper purpose. The loss of the whole, that is to say, of data which have not been acquired without the exertion of considerable scientific labour, and which seemed pregnant with beautiful germs, would then be a most discouraging consequence.

The British Association for the Advancement of Science has many times proved itself convinced of the truth of this principle. A resolution adopted by the Association in 1833, during its first meeting at Cambridge, warded off the peril just mentioned, even from a department of science whose long-established rate of progress had not been able to protect it sufficiently against such a risk. The reduction of the Greenwich observations of planets, undertaken in consequence of this resolution, and now published by order of the Lords Commissioners of the Admiralty, has been fully appreciated by all astronomers, and particularly by the late M. Bessel, who in the last moments of his life welcomed it as the beginning of a new period in astronomy. Moreover, the condition that a uniform progress of observation and calculation is equally indispensable in less-developed or only nascent branches of physical science, has been expressed by the British Association at its second meeting at Cambridge in 1845; first, by several of the members being inclined to raise the question, whether the continuation of magnetic and meteorological observations were desirable, as long as a great part of the materials collected by them are still waiting their first employment; and, secondly, by including the calculation of the Gaussian constants of terrestrial magnetism for 1829 within the sphere of their own operations, being pleased at the same time to entrust me with the superintendence of the same, and to place at my disposal the sum of £50, granted for this purpose for the year 1845 to 1846. I shall endeavour to point out in a few words the fruits this arrangement seems to promise, and the results it has already obtained.

I think we are authorised to suppose that all those phænomena which we have learned to express by numbers, with the help of remarkably accurate instruments, will at length lead us to a theory of the forces which produce them; and that, in consequence, the intrinsic value of observations on such phænomena—a value which hitherto could not be demonstrated—will then at once become most evident. It was this expectation alone which often encouraged observers to persevere in labours apparently rather tedious, and the zeal with which the meteorological and part of the magnetic variations are pursued by your members in British and colonial observatories, is, I think, attributable to the same cause. In the branches of physics which they cultivate, these observers, it is true, have still to look to futurity for both kinds of progress, viz. the discovery of an abstract theory, and the true establishment of the same by means of observed numbers. As to the first and most import

ant of these steps, they have a consolation in the fate of their predecessors in most similar labours: I allude to the long series of philosophers who devoted themselves during the first thirty years of this century to ascertaining the mean values of magnetic elements for as many points on the surface of the globe as possible, and whose undertakings are so carefully recorded by one of them—I mean Col. Sabine, in his admirable report on magnetic intensity. They too were long enough under the necessity of restricting the immediate application of their operations to refuting some evidently superficial or erroneous theoretical views, and then, after detaching from their results every accidental influence, to register them in the annals of science, as contributions to a theory which they only hoped might be attained. But M. Gauss's admirable theorem, that any terrestro-magnetical element, that is to say, any observable part of the intensity of magnetic force at a given point of the earth, or any angle formed by this force with a given plane or line, can be represented by combining with given functions of the latitude and longitude of this point a limited number (probably twenty-four) of constant quantities, and the way pointed out by him for deriving these constants from a sufficient number of observed mean values of magnetic elements, have in a short time so completely realized these hopes, that a great encouragement was held out, both to former observers of mean magnetic elements, and to those who were then, and are still employed in less-advanced branches of physics: nevertheless this encouragement was but an imperfect one. To complete it, the possibility of applying those former observations had to be changed to a reality. On this account I am inclined to think that the committee appointed to conduct the cooperation of the British Association in the system of combined magnetic and meteorological observations, have particularly contributed to the satisfaction of their own observers, by encouraging the calculation of the Gaussian constants for 1829; for, by so doing, they in the first place have confirmed their adhesion to the general principle, that no set of observations whatever must remain longer than is indispensably necessary without reduction to theory; and secondly, they have made the immediate application of the mean magnetic values for 1845, that may be furnished by the combined British and Russian observatories, the more probable, as it will then be already preceded by a similar application of the analogous values for 1829. Besides this, to prove the influence of your resolution on the department of science most directly connected with it, I may remark that a more and more exact determination of magnetic constants (the Gaussian) is equally indispensable at the present moment (and for the same reason), as the obtaining of the constants for planetary orbits was formerly, from the moment in which Kepler's and Newton's discoveries opened a possibility of arriving at them. Whatever may be the analogies once to be found in magnetism for the secular variations and other perturbations of planetary orbits, the entrance into these untouched fields of science cannot fail to be effected by fixing the actual values of Gaussian constants.

It was under these circumstances that I long ago felt it to be a debt I had contracted towards science, that the magnetic elements which I observed from 1828 to 1830, at about 650 equidistant stations, on a line encircling the globe, between latitudes 67° north and 60° south, conjointly, perhaps, with the magnetic elements that had been observed in Europe during the same years, should be fully applied to the development of the now existing theory. For the undertaking of such a work, however, it was evidently necessary to have more time at my disposal than I have ever enjoyed. M. Henry Petersen, too, a most industrious and talented young mathematician, who in 1842 had undertaken and performed at my request a small part of

this comprehensive task, found his leisure hours unequal to its completion. Now, on the contrary, the support of the British Association has enabled and induced this gentleman to suspend his other official duties for the year just expired, and to devote himself entirely to the prosecution of the work in question, in which his success will, I think, be appreciated by the Association, from the results which I have the pleasure of laying before you, accompanied by some remarks on the means employed to obtain them. What proportions these one year's results bear to the final term of the whole labour, and how far they deserve to be continued, is a subject which I shall take the liberty of touching upon at the conclusion of this paper.

The object of the calculations committed to my superintendence may be stated to consist in finding, by a sufficiently large series of observations, twenty-four corrections,—

$$\Delta g^{1,0},\ \Delta g^{1,1},\ \Delta h^{1,1},\ \Delta g^{1,2} \ldots\ldots\ldots\ldots \Delta g^{1,1},\ \Delta h^{1,1},$$

to be singly applied to the twenty-four preliminary values,

$$g^{1,0},\ g^{1,1},\ h^{1,1},\ h^{1,2} \ldots\ldots\ldots\ldots g^{1,1},\ h^{1,1},$$

which M. Gauss assigned to the constants of terrestrial magnetism, and in calculating at the same time the probable errors of the so-corrected constants. To this effect (preserving the literal denominations used in M. Gauss's theory of terrestrial magnetism, and marking by ΔX, ΔY, ΔZ, Δw, $w\Delta\delta$, $\psi\Delta i$, the differences (*theoretical value—actual* (or observed) *value*)), the following expressions have been derived:—

$$\left.\begin{aligned}
0 = {} & \Delta X + \Delta g^{1,0}\sin u - \cos u(\Delta g^{1,1}.\cos\lambda + \Delta h^{1,1}.\sin\lambda) + 2\cos u.\sin u.\Delta g^{2,0} \\
& - \cos 2u.(\Delta g^{2,1}.\cos\lambda + \Delta h^{2,1}.\sin\lambda) - \sin 2u(\Delta g^{2,2}.\cos 2\lambda \\
& + \Delta h^{2,2}.\sin 2\lambda) + 3.\Delta g^{3,0}.\left(\cos^2 u - \frac{1}{5}\right).\sin u - \left(3\cos^3 u - \frac{11}{5}\cos u\right). \\
& (\Delta g^{3,1}.\cos\lambda + \Delta h^{3,1}.\sin\lambda) - \sin u.(3\cos^2 u - 1)(\Delta g^{3,2}.\cos 2\lambda \\
& + \Delta h^{3,2}.\sin 2\lambda) - 3\cos u.\sin^2 u(\Delta g^{3,3}.\cos 3\lambda + \Delta h^{3,3}.\sin 3\lambda) \\
& + 4\left(\cos^3 u - \frac{3}{7}\cos u\right)\sin u.\Delta g^{4,0} - \left(4\cos u^4 - \frac{27}{7}\cos^2 u + \frac{3}{7}\right). \\
& (\Delta g^{4,1}.\cos\lambda + \Delta h^{4,1}.\sin\lambda) - 2\left(2\cos^3 u - \frac{8}{7}\cos u\right)\sin u.(\Delta g^{4,2}.\cos 2\lambda \\
& + \Delta h^{4,2}.\sin 2\lambda) - (4\cos^2 u - 1)\sin^2 u(\Delta g^{4,3}.\cos 3\lambda + \Delta h^{4,3}.\sin 3\lambda) \\
& - 4\cos u.\sin^3 u(\Delta g^{4,4}.\cos 4\lambda + \Delta h^{4,4}.\sin 4\lambda).
\end{aligned}\right\} (1.)$$

$$\left.\begin{aligned}
0 = {} & \Delta Y + \Delta g^{1,1}.\sin\lambda - \Delta h^{1,1}.\cos\lambda + \cos u\,(\Delta g^{2,1}.\sin\lambda - \Delta h^{2,1}.\cos\lambda) \\
& + 2\sin u(\Delta g^{2,2}.\sin 2\lambda - \Delta h^{2,2}.\cos 2\lambda) + (\Delta g^{3,1}.\sin\lambda - \Delta h^{3,1}\cos\lambda). \\
& \left(\cos^2 u - \frac{1}{5}\right) + \sin 2u.(\Delta g^{3,2}.\sin 2\lambda - \Delta h^{3,2}.\cos 2\lambda) \\
& + 3\sin^2 u\,(\Delta g^{3,3}.\sin 3\lambda - \Delta h^{3,3}.\cos 3\lambda) + \left(\cos^3 u - \frac{3}{7}\cos u\right). \\
& (\Delta g^{4,1}.\sin\lambda - \Delta h^{4,1}.\cos\lambda) + \left(2\cos^2 u - \frac{1}{7}\right)\sin u\,(\Delta g^{4,2}.\sin 2\lambda \\
& - \Delta h^{4,2}\cos 2\lambda) + 3\cos u.\sin^2 u\,(\Delta g^{4,3}.\sin 3\lambda - \Delta h^{4,3}\cos.3\lambda) \\
& + 4\sin^3.u\,(\Delta g^{4,4}.\sin 4l - \Delta h^{4,4}.\cos 4\lambda).
\end{aligned}\right\} (2.)$$

$$\left.\begin{aligned}0=&\Delta Z+2\cos u\,.\,\Delta g^{1,0}+2\sin u\,.\,(\Delta g^{1,1}\,.\,\cos\lambda+\Delta h^{1,1}\,.\,\sin\lambda)\\&+(3\cos^2 u-1)\,.\,\Delta g^{2,0}+3\cos u\,.\,\sin u\,(\Delta g^{2,1}\,.\,\cos\lambda+\Delta h^{2,1}\,.\,\sin\lambda)\\&+3\sin^2 u(\Delta g^{2,2}\,.\cos 2\lambda+\Delta h^{2,2}\,.\sin 2\lambda)+\left(4\cos^3 u-\frac{12}{5}\cos u\right).\Delta g^{3,0}\\&+\left(4\cos^2 u-\frac{4}{5}\right)\sin u\,(\Delta g^{3,1}\cos\lambda+\Delta h^{3,1}\sin\lambda)+4\cos u\sin^2 u\,.\\&(\Delta g^{3,2}.\cos 2\lambda+\Delta h^{3,2}.\sin 2\lambda)+4\sin^3 u.(\Delta g^{3,3}.\cos 3\lambda+\Delta h^{3,3}.\sin 3\lambda)\\&+\left(5\cos u^4-\frac{30}{7}\cos^2 u+\frac{3}{7}\right).\Delta g^{4,0}+\left(5\cos^3 u-\frac{15}{7}\cos u\right).\\&\sin u\,(\Delta g^{4,1}\cos\lambda+\Delta h^{4,1}\sin\lambda)+\left(5\cos^2 u-\frac{5}{7}\right)\sin^2 u(\Delta g^{4,2}.\cos 2\lambda\\&+\Delta h^{4,2}\sin 2\lambda)+5\cos 4\,.\sin^3 u\,(\Delta g^{4,3}\,.\cos 3\lambda+\Delta h^{4,3}\,.\sin 3\lambda)\\&+5\sin^4 u\,.\,(\Delta g^{4,4}\,.\cos 4\lambda+\Delta h^{4,4}\,.\sin 4\lambda);\end{aligned}\right\}\quad(3.)$$

and denoting by ΔX, ΔY, ΔZ their just-mentioned developments according to the corrections of constants,

$$0=\Delta w\quad-\cos\delta.\,\Delta X\quad-\sin\delta.\Delta Y.\quad\ldots\ldots\quad(4.)$$
$$0=w.\Delta\delta.+\sin\delta.\,\Delta X\quad-\cos\delta.\Delta Y.\quad\ldots\ldots\quad(5.)$$
$$0=\psi\,.\,\Delta i+\sin i(\cos\delta.\Delta X+\sin\delta.\Delta Y)-\cos i.\Delta Z\quad\ldots\quad(6.)$$

and then 283 numerical primary equations, relating to magnetic elements, observed on a line from Berlin to the east coast of North Asia, at the port of St. Peter and St. Paul, have been formed, by alternately recurring to one or the other of these six formulæ. For the sake of uniformity, their first term, which always meant *the value of the magnetic element calculated with M. Gauss's numbers—the observed value of the same element,*—has always been marked by the letter n, independently of its having been derived by the 1st, the 2nd, ...the 6th of these formulæ; and also the whole numerical primary equation has been represented by

$$0=n+\text{coeff.}\Delta g^{1,0}.(\Delta g^{1,0})+\text{coeff.}\Delta g^{1,1}.(\Delta g^{1,1})+\text{coeff.}\Delta h^{1,1}.$$
$$(\Delta h^{1,1})\ \ldots\ldots\ldots\ldots+\text{coeff.}\Delta h^{1,1}.(\Delta h^{1,1}),$$

independently of their origin from formulæ (1) (2) ..... or (6).

In five of the accompanying tables you will find, according to these denominations,—1. the numerical values for

log. n, log. coeff. $\Delta g^{1,0}$, log. coeff. $\Delta g^{1,1}$, log. coeff. $\Delta h^{1,1}$..... log. coeff.$\Delta h^{1,1}$†,

furnished by each single element; 2. the name, the latitude and the longitude of a station to mark the place of observation; and 3. one of the letters X, Y, Z, w, δ or i, which respectively indicate that the observed element has been the northern or the western component of horizontal force, the vertical force, the whole horizontal force, a declination or an inclination*. In the three last cases in which therefore n denotes the value of Δw, of $w\Delta\delta$, or of $\psi\Delta i$‡, it must still be noticed that the values of the declination (δ) in the first, and respectively of the horizontal force (w), or of the total force (ψ) in

* It is understood that, according to M. Gauss's memoir, the meaning of the letters employed is,—

X Northern horizontal force.	δ Declination.
Y Western horizontal force.	i Inclination.
w Total horizontal force.	u North polar distance of the station.
Z Vertical force.	λ Longitude east from Greenwich of the station.
ψ Total force.	

† Instead of log. coeff. the further abbreviation l.c. being usually employed.

‡ The arcs $\Delta\delta$ and Δi being previously changed to the ratio of their sines to unity.

the two other, being only approximately required for this purpose, have been merely calculated by theory, viz. by those values of constants which we are about to correct.

The correctness of the numbers in those 283 primary equations for the twenty-four unknown, has then been controlled by determining the theoretic values of the X, the Y, the Z, or of the two or three of them that were required for the composition of w, of tang δ or tang i, a second time in a somewhat different way. It consisted in calculating according to

$$X = F(u) + F^{I}(u)\cos\lambda + F^{II}(u)\sin\lambda + F^{III}(u)\cos 2\lambda + \ldots\ldots\ldots + F^{VII}(u)\cos 4\lambda + F^{VIII}(u)\sin 4\lambda,$$

or to a quite analogous expression for Y and Z, for which the *numerical values* contained in $F(u)$, $F^{I}(u)$ . . . . . $F^{VIII}(u)$ are given as resulting from the preliminary values of the twenty-four constants in M. Gauss's theory of terrestrial magnetism, § 27.

This part of the task being completed, the second, and by far the most laborious one, consisted in forming out of the coefficients in each primary equation $\frac{25\times 26}{2}=325$, and therefore altogether $325\times 283=91975$ products of two factors, each according to this form,—

$$\begin{array}{l} un,\ n.(c.\Delta g^{1,0}),\ n(c.\Delta g^{1,1}),\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ n.(c.\Delta g^{1,1}),\ n(c.\Delta h^{1,1}),\\ (c.\Delta g^{1,0}).(c.\Delta g^{1,0}),(c.\Delta g^{1,0}).(c.\Delta g^{1,1}),\ldots(c.\Delta g^{1,0}).(c.\Delta g^{1,1}),(c.\Delta g^{1,0}).(c.\Delta h^{1,1}),\\ (c.\Delta g^{1,1}).(c.\Delta g^{1,1}),\ \ldots\ (c.\Delta g^{1,1}).(c.\Delta g^{1,1}),\ (c.\Delta g^{1,1}).(c.\Delta h^{1,1}),\\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\\ \vdots\qquad\qquad\qquad\vdots\\ (c.\Delta g^{1,1}).(c.\Delta g^{1,1}),\ (c.\Delta g^{1,1}).(c.\Delta h^{1,1}),\\ (c.\Delta h^{1,1}).(c.\Delta h^{1,1}). \end{array}$$

The 283 products, assembled under each of these 325 titles, were then separately summed up, and by this means (marking by [ ] a sum of analogous terms) the twenty-four final equations of the following form were obtained:—

$$\begin{array}{l} -[n.(c.\Delta g^{1,0})] = [(c.\Delta g^{1,0}).(c.\Delta g^{1,0})].\Delta g^{1,0} + [(c.\Delta g^{1,0})(c.\Delta g^{1,1})].\Delta g^{1,1} + \ldots\\ \qquad\ldots\ldots\ldots\ldots + [(c.\Delta g^{1,0})(c.\Delta g^{1,1})].\Delta g^{1,1} + [(c.\Delta g^{1,0})(c.\Delta h^{1,1})].\Delta h^{1,1},\\ -[n.(c.\Delta g^{1,1})] = [(c.\Delta g^{1,1}).(c.\Delta g^{1,0})].\Delta g^{1,0} + [(c.\Delta g^{1,1})(c.\Delta g^{1,1})].\Delta g^{1,1} + \ldots\\ \qquad\ldots\ldots\ldots\ldots + [(c.\Delta g^{1,1})(c.\Delta g^{1,1})].\Delta g^{1,1} + [(c.\Delta g^{1,1})(c.\Delta h^{1,1})].\Delta h^{1,1},\\ -[n.(c.\Delta h^{1,1})] = [(c.\Delta h^{1,1})(c.\Delta g^{1,0})].\Delta g^{1,0} + [(c.\Delta h^{1,1})(c.\Delta g^{1,1})].\Delta g^{1,1} + \ldots\\ \qquad\ldots\ldots\ldots\ldots + [(c.\Delta h^{1,1})(c.\Delta g^{1,1})].\Delta g^{1,1} + [(c.\Delta h^{1,1})(c.\Delta h^{1,1})].\Delta h^{1,1},\\ \qquad\vdots\qquad\qquad\qquad\qquad\qquad\vdots\\ -[n.(c.\Delta h^{1,1})] = [(c.\Delta h^{1,1})(c.\Delta g^{1,0})].\Delta g^{1,0} + [(c.\Delta h^{1,1})(c.\Delta g^{1,1})].\Delta g^{1,1} + \ldots\\ \qquad\ldots\ldots\ldots\ldots + [(c.\Delta h^{1,1})(c.\Delta g^{1,1})].\Delta g^{1,1} + [(c.\Delta h^{1,1})(c.\Delta h^{1,1})].\Delta h^{1,1}. \end{array}$$

The numerical expressions of these equations will be found in the table marked VI. Hitherto they have been controlled by the calculation leading to them from the primary equations, being repeated a second time in the same manner as the first, but with the suppression of one decimal figure in the products and in their sums. To obviate the danger, arising from the addition of such extensive rows of numbers, lest the compensation of opposite errors might produce an illusory agreement, M. Petersen, besides the formation of new primary equations, has proceeded to subject these final equations to another kind of control,—I mean the process usually employed in similar

cases, and which consists in the formation for each primary equation of a supplementary term s, equal to the sum of the other, viz. in one case, in the calculation of

$$s = \text{coeff.}\ \Delta g^{4,0} + \text{coeff.}\ \Delta g^{4,1} + \text{coeff.}\ \Delta h^{4,1} + \ldots\ldots + \text{coeff.}\ \Delta g^{1,1} + \text{coeff.}\ \Delta h^{1,1},$$

whereby we obtain as controlling equations,

$$[sn] = [n.c.\Delta g^{4,0}] + [n.c.\Delta g^{4,1}] + [n.c.\Delta h^{4,1}] + \ldots + [n.c.\Delta g^{1,1}] + [n.c.\Delta h^{1,1}],$$

$$[s.c.\Delta g^{4,0}] = [(c.\Delta g^{4,0})(c.\Delta g^{4,0})] + [(c.\Delta g^{4,0})(c.\Delta g^{4,1})] + \ldots + [(c.\Delta g^{4,0})(c.\Delta h^{1,1})],$$

$$\vdots \qquad\qquad\qquad\qquad \vdots$$

$$[s.c.\Delta h^{1,1}] = [(c.\Delta h^{1,1})(c.\Delta g^{4,0})] + \ldots\ldots\ldots\ldots + [(c.\Delta h^{1,1})(c.\Delta h^{1,1})],$$

independently of the extension which is given to the sums marked by [ ].

If we now consider, in the first place, the linear primary equations contained in the Tables annexed, we shall find that the values of the Gaussian constants hitherto accepted sufficiently approximate to the truth to authorise the supposition from which we start, that the powers of their corrections superior to the first can be neglected; but, on the other hand, that these values are still so erroneous, that the elements calculated by them differ from the empirical ones by far more than can be ascribed to errors of observation, and in quite another manner than would arise from local irregularities of terrestrio-magnetic power. Indeed we see that when the places of observation are in similar parts of the globe, the values of n belonging to them remain nearly enough equal to each other; whereas on the longitudes of the places increasing, these values of n are gradually lessened, and at length replaced by a series of values with opposite signs. Of course, to observe this regularity of progress, we must only compare such values of n as relate to magnetic elements of a similar character; as for instance, all to x, or all to w, and so on.

The value $[nn] = 233423$, marked in the Table of Final Equations as resulting from 283 equations, shows that for the part of the earth on which the observations hitherto considered have taken place, the mean difference between an observed magnetic element and the corresponding calculated one amounts to 29, the intensity of the whole force at London being = 1372; and in agreement with this result, we find, for example, by immediate inspection of the Table of Primary Equations,—

The mean difference	Lat. 56.	56.	67.	54.	59.	56.	
	Long. 43.	60.	67.	100.	145.	222.	
In northern horizontal force	+46	+39	+23	− 6	−28	+35	in whole horizontal force.
In western horizontal force	+18	+19	+40	0	−25		
In perpendicular force	+11	+13	+35	−15	+30	+38	

The concluding table contains besides, as already mentioned, twenty-four final equations for the twenty-four unknown quantities, by which, mathematically speaking, the whole problem in question would appear to be ready for a definitive and now most easy solution. In practice, however, this is evidently far from being the case. Thus indeed it is plain, even at a first glance, that each observation, hitherto registered, has already contributed to the solubility of the problem all that it will ever be able to do; there is not in this circumstance alone a sufficient reason for that solubility being reached, and then that, on the contrary, the probability of the value to

be obtained for any one of the twenty-four unknown quantities, f
ample, $\Delta g^{1,1}$ depends entirely on its *weight*, that is to say, on the i
tude of the coefficient with which this quantity remains in the eq
containing at the origin the terms $\ldots\ldots + [(c.\Delta g^{1,1}).(c.\Delta g^{1,1})].\Delta g^{1,1}$
the elimination of the twenty-three others; and that these weights, as is
shown, will only become sufficiently extensive when there are neith
nor more of the unknown quantities whose coefficients remain in a eq
or in a nearly constant relation in the whole series of primary equatio
butary to the final ones. Hence the examination in this same respect
above expressions for Δx, Δy, ... $\psi\Delta i$, will easily show that by
of the similarity of the latitudes in which by far the greatest part of
servations till now calculated have been effected, the solution of th
equations as hitherto obtained would give but a very trifling weight to
all the corrections we are seeking for, and therefore be still without i

Even the seventy elements that, according to date of observation,
next to the 283 finished ones, and for which M. Petersen has also
accomplished the primary equations, will, by their contributing to t
ones, most sensibly improve them in respect of solubility. Indeed
opposition to the now finished ones, these latter elements relate to p
a line rather northern than eastern in its direction, and extending fr
latitude north to about the equator. It is therefore precisely those u
quantities whose coefficients have hitherto exhibited the least variat
followed in their varying a course parallel with that of the coeffic
other unknown ones, that will vary the most, both relatively and ab
speaking, in the set of primary equations next to be formed, and t
add to the final equations just what is requisite for increasing the w
each of the quantities sought for and thereby preparing their due sep

M. Petersen will at all events subjoin, in the course of the ensuing
this next continuation of his present labour, which I shall then forwar
Association.

It is plain, notwithstanding, that even then we shall not have rea
most favourable state which our fund of observations for the year 182
allow of attaining in the knowledge of the Gaussian constants for t
year. Indeed even then, by substituting, as could be effected throu
further patronage, a full execution of the task to a but partial one, th
of observation contributing to the final equations may be trebled, a
is still more important, a considerable improvement be attained in
petition over the globe.

I thought it my duty to submit to the Association my opinion
benefits to be derived from the continuation of M. Petersen's labours,
it to their decision whether they will consider it advisable to grant h
further support in devoting himself entirely to the prosecution of hi

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On the Progress, present Amount, and probable future Condition of the Iron Manufacture in Great Britain. By G. R. Porter, F.R.S.

In obedience to the request of the Council of the British Association, made at its meeting in June 1845 at Cambridge,—a request from that body being equivalent to a command,—I avail myself of the first moment of leisure that has since presented itself, to investigate the condition of the iron manufacture in Great Britain.

The incessant claims upon my time, of public duties, which have called in their performance for the most anxious and unremitting labour, throughout all of the present year that has hitherto elapsed, may perhaps be allowed to plead in excuse for the imperfect manner in which I am able to perform my task. I wish, most sincerely, that it had been otherwise, and that it had been possible to devote to its accomplishment an amount of time and a degree of research that might have enabled me to present a work more worthy of the acceptance of this body, and better proportioned to the importance of the subject.

It was, doubtless, a conviction of the great and growing influence which the progress of the iron manufacture must exercise upon other important branches of our national industry, that led the Council of our body to desire information concerning it, and all that has since arisen in the course of our legislation has given additional interest to the subject, so that it has become more than ever of consequence to know the actual condition of this great branch of our industry, and of the capabilities which present themselves for its increase. The enormous demand for iron caused by the general and simultaneous construction of railways all over this kingdom, and not here only, but in various parts of Europe and in the United States of America, and also by their promised extension to India, is calculated to produce much of anxious inquiry into the subject, in order to ascertain, in the first place, whether, and in what way, that enormous demand can be met, and then to satisfy ourselves that through the cessation of that demand, which from its nature must be in a chief degree temporary, we may not be exposing to ruinous depreciation establishments for the formation of which vast capitals have been and will be sunk, in which many skilled workmen are trained, who during the continuance of the existing great demand will be receiving high wages, but who when it ceases may, many of them, be thrown out of employment, and who must be so, unless some new and permanent uses can be found for the produce of their industry.

The object of the present inquiry does not call for any research into the remote history of the iron manufacture. It will not assist us in the solution of the questions now pressing upon our attention, to ascertain whether, in centuries preceding the Christian æra, when the Phœnicians traded with our ancestors for tin, the Britons did, as some writers have assumed, know and practise the manufacture of iron. Certain it is, that the rise of that manufacture upon any scale deserving of notice as a national object, dates from a time within the memory of persons now living. In 1788 the whole quantity of pig-iron made in England and Wales is said to have amounted to no more than 61,300 tons, of which quantity 48,200 tons were made with coke of pit-coal, and the remaining 13,100 tons were still made with charcoal (see Appendix No. 1). In the same year the production in Scotland did not exceed 7000 tons. In Ireland charcoal-iron was made on a moderate scale during the seventeenth century. Sir William Petty tells us in his 'Political Anatomy of Ireland,' that in 1672 the quantity of iron made there was about 1000 tons, giving employment to about 2000 persons of both sexes. Works

established by Sir William Petty in the county of Kerry in 1660, continued to be carried on until the exhaustion of the timber in the neighbourhood brought them to a stand, and in 1788 there does not appear to have been any iron-work in existence in Ireland.

About this time the iron-masters in Great Britain began to avail themselves of Mr. Watt's improvements of the steam-engine, and were thus enabled greatly and rapidly to increase the productive power of their works, so that in eight years from 1788 the quantity of British-made iron was nearly doubled. An inquiry made in 1796, consequent upon the proposal of Mr. Pitt, which was afterwards abandoned, to place a tax upon coal at the pit's mouth, showed the make of British iron to be then—

In England and Wales...	108,993 tons.
In Scotland	16,086 tons.
Together	125,079 tons. (See App. No. 2.)

Ten years later, in 1806, it was proposed to tax the production of iron, and again on that occasion an account was taken of the number of furnaces and the quantity of iron produced, which was found to have been more than doubled in ten years; the production being

In England and Wales...	234,966 tons.
In Scotland	23,240 tons.
Together	258,206 tons. (See App. No. 3.)

Of this quantity it was stated that about 95,000 tons were converted into bars and plates, and that the capital engaged in the manufacture amounted to £5,000,000. The proposed tax was so powerfully opposed in the House of Commons, that the bill was carried through the Committee by a majority of only ten, and the measure was abandoned.

The next account of this manufacture which has been given, was prepared by Mr. Francis Finch, formerly member for Walsall, and had reference to the year 1823. From that account (see App. No. 4) it appeared that in seventeen years the make of iron in Great Britain had been increased from 258,206 tons to 452,066 tons. Between 1823 and 1830 there were erected ninety-six new furnaces; and in the latter year it was found, on a further examination by Mr. Finch, that the quantity of pig-iron made in Great Britain amounted to 678,417 tons (see App. No. 5). Our confidence in the correctness of the quantities here stated should be confirmed by their having been adopted in his evidence before the Committee on Import Duties in 1840 by Sir John Guest, whose authority upon this subject is conclusive.

From this time (1830) a series of improvements has been introduced into the processes of making iron, which has had the effect of improving the quality of the metal and of materially œconomising the cost of its production. One of the most important of these improvements was made the subject of a patent in 1829 by Mr. Neilson of Glasgow, and consisted in the artificial heating of the air previously to its being passed into the furnaces. The effect of this plan in saving fuel has been most remarkable. In 1829, at the Clyde Iron Works, where Mr. Neilson's experiments were made, and in which his patent was first adopted, it required more than 8 tons of coal, when converted into coke, to produce 1 ton of cast iron. This was when the air was forced into the furnace at its natural temperature. By heating the air to 300° Fahrenheit preparatory to its introduction, it became necessary to consume for each ton of iron produced only 5 tons 3½ cwt. of coal converted into coke; but in heating the air to the required degree, nearly

8 cwt. of coal was consumed. The saving was thus found to be 2½ tons of coal for each ton of iron. Thus encouraged, further experiments were made. The previous heating of the air was raised to 600° Fahrenheit, and it was then found, not only that a further great œconomy was produced in the fuel, but that coal could be used for smelting in its raw or uncoked condition. It was further discovered that the same blast-machinery, when the air was thus heated, sufficed for a greater number of furnaces, so that the power necessary for three furnaces, when cold air was employed, became ample for four furnaces of equal size when the air was previously heated. The result may be thus stated :—

In 1829, using coke and cold air, each ton of iron required for its production 8 tons 1 cwt. 1 qr. of coal.
In 1830, using coke and heated air, each ton of iron was made with 5 tons 3 cwt. 1 qr. of coal.
In 1833, using raw coal and heated air, each ton of iron was made with 2 tons 5 cwt. 1 qr. of coal.

The saving in fuel is thus seen to amount to 72 per cent.

The effect of the hot-blast upon the quality of the iron produced has been the object of many experiments to determine. As those experiments were in great part undertaken at the instance of the British Association, and as their results have been published from time to time in its Transactions, it cannot be necessary to notice them further here. Mr. Neilson's invention was for a long time greatly decried, and to this day it is the practice with some few of our leading engineers, when drawing specifications for works, to forbid the use of hot-blast iron. Under these circumstances, the introduction of this plan has been by no means universal in the iron-works of England and Wales, although it is otherwise in Scotland, where the increased make of iron, from 37,500 tons in 1830, to nearly 500,000 tons in the past twelve months, may be in great part, if not altogether, ascribed to the œconomy which Mr. Neilson's plan has occasioned. But for the introduction of that plan, we should in all likelihood not have witnessed the unequalled development exhibited during the past fifteen years in this, which has now become one of the greatest branches of our national industry. Without this discovery our railroad system could not have marched forward with such giant strides, and in all probability the application of iron to the building of ships,—an application from the extension of which, in future years, so many advantages may be made to arise,—might have continued unthought of.

In a letter which has reached me while writing, from a most intelligent iron-master in the North of England *, the subject is thus noticed :—

"Previously to this invention, metal was made with such coal only as was easily destructible before the blast, thereby admitting a greater quantity of air into the furnace. Air is the food of fire. Coals of a stronger or more bituminous character were not serviceable; the current of cold air at the Tuyeres had the effect of caking the coal and choking the admission of air, by which the process of reduction was stopped. But when Mr. Neilson introduced his method the difficulty was conquered. By heating the air up to 600° Fahrenheit, the caking at the Tuyeres no longer took place; the air entered freely into the furnace, and coal hitherto unserviceable was enlisted into the service of mankind, and applied to the great improvement of their condition.

"It was pretended that the metal made with hot-blast was not so good; that it was weaker; and for a long time it was *tabooed* in all contracts; but this delusion is gradually giving way to truth. There was no foundation for such prejudice. It is known that air does not burn until it reaches 3000°

* Charles Perkins, Esq.

Fahrenheit; the raising of it to 600° before admission to the furnace was nothing, nor did it destroy any of its elementary qualities; it only secured its admission and ensured its regularity of action in the process of reduction. This was an increase of man's power over elementary matter: it is by the additions to and the increase of this power that men will in time accomplish a greater and more powerful condition."

The disinclination to adopt an innovation, which as we have seen in this case of the hot-blast, has not been entirely overcome by more than fifteen years' experience of its advantages, has not been confined to that instance, but has been allowed for a much longer period to influence, in another case, the proceedings of our iron-masters. It was as long ago as 1801, that Mr. David Mushet, to whom the world is greatly indebted for his scientific researches and his practical exertions in this important branch of metallurgy, discovered when crossing the river Calder, in the parish of Old Monkland, a description of ironstone, to which the name of black-band, or Mushet-stone, has been given. For many years following this discovery the black-band was used only in the Calder Iron Works, which were established in 1800 by Mr. Mushet, and it was not even there employed alone, but was used in combination with other iron ores of the argillaceous class. It was not until 1825 that it was first used alone by the Monkland Company, whose success in the experiment led gradually to its adoption by other establishments, and to the erection of additional works.

Mr. Mushet, in his 'Papers on Iron and Steel,' p. 128, thus describes the advantages of this kind of ironstone:—

"Instead of 20, 25 or 30 cwt. of limestone formerly used to make a ton of iron, the black-band now requires only 6, 7 or 8 cwt. to the production of a ton. This arises from the extreme richness of the ore when roasted, and from the small quantity of earthy matter it contains, which renders the operation of smelting the black-band with hot-blast more like the melting of iron than the smelting of an ore. When properly roasted, its richness ranges from 60 to 70 per cent., so that little more than a ton and a half is required to make a ton of pig-iron; and as one ton of coal will smelt one ton of roasted ore, it is evident that when the black-band is used alone, 35 cwt. of raw coal will suffice to the production of one ton of good gray pig-iron."

This calculation is strongly corroborated by a statement which was produced by Dr. Watt to the Statistical Section of the Association at Cambridge, from which it appeared, that to make 400,400 tons of iron in the counties of Lanark, Ayr, Stirling and Clackmannan, the quantity of coal consumed was 934,266 tons, or 2 tons 6 cwt. 2 qrs. 18 lbs. for each ton of iron, part of which is the produce of argillaceous ores.

The statement of these discoveries appears necessary in order to account for the great and rapid extension given since 1830 to the production of iron in this kingdom, and especially in Scotland.

In 1836 every iron-work in Great Britain was visited, and an account taken of its produce, by a highly-gifted gentleman, M. F. Le Play, "Ingénieur en chef," employed in the Ministry of Public Works at Paris, under whose direction are made the yearly reports describing the progress of mining industry in France, of which I have on former occasions availed myself in preparing papers read before this Section of the Association. The result of his inquiries showed that in that year the quantity of iron made reached to 1,000,000 tons, an amount then deemed almost incredible, but which in the years immediately following was greatly exceeded. In his 'Papers on Iron and Steel,' to which reference has already been had, Mr. Mushet states (p. 421) that the quantity of British iron made in 1839, was 1,248,781 tons (See App. No. 6).

In the following year a very elaborate inquiry into this subject was made by Mr. William Jessop of the Butterley Works in Derbyshire, and the result of his inquiries was printed by him for private distribution. His statement embraces every iron-work in Great Britain, and gives the number of furnaces in blast and out of blast, with the weekly produce of each establishment. From Mr. Jessop's tables it was shown that the number of furnaces in blast in that year (1840) was 402, and the number out of blast 88; the weekly produce of the 402 furnaces being 27,928 tons, and consequently the yearly produce, taken at 50 weeks' working, 1,396,400 tons. In the production of this quantity Mr. Jessop states that there were consumed 4,877,000 tons of coal, being at the rate of 3 tons in Scotland, and 3 tons 12 cwt. in England and Wales, for each ton of iron. This was exclusive of the coal used in converting pig-iron into wrought iron, and which he sets down at 2,000,000 tons additional (see App. No. 7). At the time Mr. Jessop's account was taken, it appeared that out of 420 furnaces erected in England and Wales, there were 82, or 1 in 5, out of blast, and that of 70 furnaces in Scotland, 6, or 1 in 11, were in that condition. The rapid increase of this manufacture during the preceding ten years forbids the belief that this large number of furnaces could have been idle through dilapidation. In fact, the country was then suffering under an amount of commercial depression of no ordinary character, and which continued to press heavily upon almost every branch of its industry, until the abundant harvest of 1844, joined to the effect of the fiscal reforms introduced in 1842, caused the return of healthiness to our trading interests. The continuance of the depression, which had no doubt extinguished so many of the furnace fires in 1840, caused still more of them to be put out of blast in the years immediately following, and it was shown by a statement drawn out under the direction of an association of the iron-masters of Yorkshire and Derbyshire, that the quantity of iron made in the first six months of 1842 in Yorkshire, Derbyshire, Staffordshire, Shropshire, South Wales and Scotland did not exceed 523,214 tons, or at the rate of 1,046,428 tons per annum. The quantity of iron made in those divisions of the kingdom in 1840 was, according to Mr. Jessop's statement, 1,343,400 tons, so that the diminution of production was at the rate of more than 22 per cent., which rate was probably experienced throughout the kingdom; and in this case the whole quantity of iron made in 1842 did not much exceed one million of tons, the quantity ascertained by M. Le Play to have been made in 1836.

A great impulse had been given at that time to this branch of industry by the demand arising from the construction of railways. This impulse, and the subsequent depression, may be easily inferred from the following statement of the number of railway acts passed in each year from 1831 to 1843, distinguishing such as were for new lines from those which authorized extensions or amendments in former acts, and giving the amount of capital authorized by Parliament to be raised under those acts.

Years.	Acts passed for		Capital authorized.
	New Lines.	Extensions,&c.	£
1831.	5	4	1,799,873
1832.	5	4	567,685
1833.	5	6	5,525,333
1834.	5	9	2,312,053

TABLE (*continued*).

Years.	Acts passed for		Capital authorized.
	New Lines.	Extensions, &c.	
			£
1835.	8	11	4,812,833
1836.	29	6	22,874,998
1837.	15	27	13,521,799
1838.	2	17	2,096,198
1839.	3	24	6,455,797
1840.	—	24	2,495,032
1841.	1	18	3,410,686
1842.	4	18	5,311,642
1843.	5	19	3,861,350

We see from these figures, that in the two years 1836 and 1837, Parliament passed 77 railway bills, of which 44 were for new lines, and that the capital thus authorized to be raised, amounted to more than 36 millions of money. The length of the lines then sanctioned amounted in the aggregate to nearly 1200 miles, and would call for the production of more than 500,000 tons of iron. The price of bar-iron, which in 1834 had been 6*l.* 10*s.* per ton, and in 1835 was 7*l.* 10*s.*, advanced in 1836 to 11*l.*, and this gave a powerful stimulus to the extension of the manufacture. So great a rise in the market value of the metal checked its use however for a great variety of purposes, and when, in the years following 1837, the railway speculation so far subsided, that only 15 acts were passed for the construction of new lines in the six years from 1838 to 1843, the price of iron fell as rapidly as it had previously risen, and it could with difficulty be sold at less than half the price which it commanded in 1836. In this state of things, the iron-masters sought to lighten their loss by limiting the production, rather than by forcing their goods into use by lowering the price. This appears to have been done to a greater extent in England and Wales than in Scotland, where for reasons already explained, the cost of production had been so lessened as to enable the iron-masters to work to a profit at prices by which their English competitors were losing on every ton they brought to market.

Since Mr. Jessop made his statement in October 1840, not any attempt has been made to ascertain the progress of the iron manufacture throughout England and Wales, from which any result can be confidently given. In Scotland, where the principal extension has occurred, several statements of the kind have been put forward. One of these, the correctness of which has been generally admitted by those whose knowledge upon the subject should give weight to their opinion, states the number of furnaces in blast in March 1845, and the weekly and yearly produce from the same to have been 76 furnaces, yielding 8250 tons of iron weekly, or in the year of 50 weeks, 412,500 tons. At that time there were, according to this statement, 22 more furnaces built and building, and the whole of these it was expected would be in blast in the course of 12 months from that time. It is stated by a respectable firm in Glasgow, that in December 1845, there were 87 furnaces in blast in Scotland, the number at the end of 1844 having been 69; the increased make of pig-iron in 1845 as compared with 1844 is stated at 60,000 tons. The lowest price at Glasgow in January 1844 was 40*s.* per ton, and the highest price for the year, caused in great part by the purchases of spe-

culators tempted by that extremely low price, occurred in April, when the quotation stands at 65*s.* per ton: in September the price was again reduced to 50*s.*, and the average price of the year was 55*s.* 6*d.* per ton. In 1845, the lowest price, which also occurred in January, was 60*s.*, and in March the price had advanced to 100*s.*; in May purchases were freely made at 110*s.*; and we cannot wonder that with a rise in price equal to 175 per cent., so great a stimulus should be given to the extension of iron-works. On the authority of the same firm, it is stated, that the number of furnaces in blast, which at the end of 1845 was 87, was on the 30th of June 1846 increased to 97, and that the computed make of pig-iron in Scotland, in the first six months of the present year, is 260,000 tons, equal to 520,000 tons in the year, showing that the production has been more than doubled in the six years since 1840.

I have before me a detailed account of the iron-works of Scotland in August 1846, which gives 105 as the number of furnaces in blast, 21 as those out of blast, in addition to 11 more building. The weekly make of pig-iron at the 105 furnaces is said to be 11,010 tons, equal to 550,050 tons per annum; estimating that each furnace is in action during 50 weeks. This account is in part corroborated by a table kindly sent to me by Dr. Watt, of the works in Lanarkshire, and which places the yearly produce of that county at 390,000 tons. It is further stated, that notwithstanding the great increase in the quantity made, according to the concurrent testimony of all parties, the stock of iron in the hands of the makers and dealers has materially decreased.

The stock in Glasgow at the end of 1845 was 210,000 tons and on the 30th of June 1846, only	140,000
Decrease.....	70,000 tons.

It may be assumed that this increase of production, although it may have been at first called forth by speculation, has not been sustained by those means, since the stock has thus diminished in the face of that increase, while the price has been declining. In January it was 80*s.* and in June 68*s.* per ton.

A statement which appeared in the 'Glamorgan Gazette' computed the make of iron in 1843 at 1,210,550 tons, of which quantity 238,750 tons were assigned to Scotland. The entire quantity was stated to have been the produce of 339 furnaces in blast, while there were said to be 190 furnaces out of blast in different parts of the kingdom. Another statement, communicated to me by Mr. Buckley (Member of Parliament for Newcastle), differs but slightly from that which was inserted in the 'Glamorgan Gazette,' the total quantity made being given as 1,215,350 tons (see App. No. 10).

In the absence of any authentic statement of the make of iron in England and Wales at this present time, an attempt has been made by correspondence to ascertain the facts as they exist in different localities. The result of inquiries thus conducted cannot have the same value as the investigations made by Mr. Jessop in 1840, but is offered here as the best which it has been in my power to produce.

It is given as the opinion of several most intelligent iron-masters whom I have consulted, that nearly all the increased production of iron in this kingdom since 1840, has been drawn from Scotland. It is true that in some of the Scotch works there is already experienced a short supply of materials, but on the other hand, new fields are discovered and brought into working. Mr. Jessop states, that "a new field of coal and iron has been opened out in Ayrshire, but not so favourable as the Airdrie and Coalbridge district." The great demand at present experienced, and that which is sure to follow from the extent of the railway projects which have received legislative sanction in 1845 and 1846, have naturally stimulated every establishment to its utmost

point of production. But in order to add materially to the make of iron, a great variety of circumstances must be brought to concur. One of the greatest difficulties with which the manufacturers have to contend in such circumstances is offered by the workmen, who naturally enough, perhaps, strive to obtain for themselves the largest possible share of the increased value of that which they produce. To be of much use in any branch of this manufacture a man must have undergone a season of instruction, and as the number of skilled workmen is limited, these, whenever any great or unwonted demand arises, hardly know how to set limits to their demands. On this subject, a recent number of the 'Merthyr Guardian' contains the following paragraph.

"Prosperity in the Iron Trade.—We believe the iron trade in this district was rarely ever known to be in a more thriving state than at the present time. Forgemen and puddlers realize from 10*l.* to 18*l.* per month. But this state of prosperity brings its attendant snare, inasmuch as the surplus which should be accumulating in the Savings' Banks, is in too many cases squandered in debauchery or lavished in vice. The state of things calls loudly for a remedy."

This complaint will not surprise us when we call to mind the fearful description of the state of the population of Merthyr, read before this section of the Association at Cambridge, by Mr. Kenrick. But the same complaint is made in other quarters, and there is but too much reason to fear that it might be universally preferred. In a letter now before me, an extensive iron-master in the north of England writes on the 15th of August last,—"The cost of making iron from the recent spirt of prosperity has increased so enormously that the 'prosperity' has well-nigh ruined many makers! wages are so ruinously raised."

A gentleman writes from Scotland in June 1845,—"This is the present position of the trade. The speculators were first bitten by the mania of anticipated consumption; then the masters took the fever, and, as was to be expected, the workmen follow, and say they must have a rise of wages equivalent to the 110*s.* price. It is nothing to them that iron has again fallen; they say, first put us up equivalent to the high price before you can ask us to conform to the present. The iron-master will therefore find that he must give the wages corresponding to 110*s.*, although he may sell at 70*s.* or less." It is understood that chiefly from this cause the cost price of iron in Scotland has been increased about 15*s.* per ton.

May we not reasonably allow ourselves to indulge the hope, that at some future, and perhaps not very distant day, the two classes of employers and workmen may come to the better understanding of their mutual interest, so that the sun of prosperity, whenever it arises, may shine equally for both?

Statements were inserted in the course of last year in the 'Mining Journal,' and were made the subject of remark by different persons without impugning their accuracy, to the effect that the make of iron in Great Britain during 1845 would amount to about 1,330,000 tons. If the statement concerning the production in Scotland already mentioned should be correct, this would leave for the make in England and Wales 917,500 tons, being 134,000 tons less than the quantity stated by Mr. Mushet as made in 1839, and 238,000 less than the produce of 1840, as given by Mr. Jessop. The increase in Scotland during the five years was, on the other hand, 171,500 tons, thus leaving the whole produce of 1845 less than that of 1840 by 66,500 tons.

It will doubtless appear extraordinary, that with so much cause for increasing the quantity as had arisen last year out of the actual and anticipated demand for railway purposes, the produce in England and Wales should not

at least have overtaken that obtained in 1840, and that it had not done so calls for explanation. In the endeavour to obtain this I have been met by statements which might appear to be in some respects somewhat contradictory of each other, the different writers representing matters as presented to their own views and experience, and without possessing that general acquaintance with the facts existing in other districts which it is so desirable to attain. One most highly intelligent iron-master whom I have consulted writes, "I consider now," that is, since the discovery of the hot-blast system, "that all the ironstone and coal of this country is applicable to the production of iron. I fear however that the deposits of ironstone exceed very much those of coal, and that the increasing demand upon this latter article will before many years show its effects. I think in Staffordshire they already feel a want in the high price of coal, and the iron trade seems migrating northward, where coal is more abundant and different deposits of ironstone are continually discovered." The gentleman who thus writes is interested in iron-works in the county of Northumberland, where the make of iron has increased and is increasing greatly and rapidly, but still not sufficiently to compensate for the falling off of production elsewhere.

Another gentleman, from whom I have received great assistance in my inquiries, writes, "In some of the localities in Scotland there is beginning to be a great scarcity of ironstone, several furnaces being recently put out in consequence; and in Staffordshire still more so. People's ideas about increase of make of iron travel much faster than the reality. In fact, during 1845 great numbers of the furnaces in Staffordshire were going on *half*-quantity, simply from want of materials; this *I know*." It is corroborative of this representation, that a powerful iron company, having works in Staffordshire, has for some time had two new furnaces completed without putting them in action.

From a third correspondent, whose interest is in the great iron district of South Wales, I hear of so great a number of new works building in Durham, Cumberland, Northumberland and Scotland, that any account taken of the produce in those districts, even so recently as last April, must necessarily be very imperfect. He adds, "They are progressing so rapidly, and can produce iron at such a cheap rate in these new iron districts, as to lead to the conclusion that ultimately the principal seat of the iron manufacture will be removed from South Wales to the North of England and Scotland."

On the other hand, Mr. Mushet, whose acquaintance with the subject is probably of a more general nature than that of my correspondents previously quoted, writes so recently as the 16th of August in the present year,—"The principal object in the iron trade which now attracts attention is the recent discovery of an extensive district of black-band ironstone, ranging from beyond Cwm Avon, through Maesteg, towards the valley of the Taffe. The two principal beds or veins of black-band lie high in the coal series, and in this respect differ from the Beaufort black-band, which was found over the lowest coal, and from the Scotch, which was found descending in the coal-series at various depths. These beds measure fifteen inches each in thickness, and will each yield fully 3000 tons per acre. The lower bed contains 40 per cent. of iron, and is put raw into the furnace; the other is previously roasted, as it contains more shale, and when so roasted yields the same quantity of iron as the other when raw. As this range of minerals occupies both sides of the line from Cwm Avon to Cwm Taffe, large tracts of black-band ironstone must unavoidably be found, and it may not be hazardous to pronounce that this in time may rival Merthyr, and become an extensive iron-making district, probably the *Lanarkshire* of South Wales." Mr. Mushet furnishes a list of fourteen furnaces in which this black-band ironstone is

partly used, and mentions three other furnaces now building in which it will be employed.

Referring to the counties of Durham and Northumberland, Mr. Mushet gives a list of thirty-five furnaces where twenty years ago only one blast-furnace, at Chester-le-street, was known to exist; and he mentions, but not as of his own knowledge, another source of supply as about being brought forward into notice from the spoil and waste of the lead-mines in Weardale, "which are now worked and have been so for ages." He says, "The rider of the lead-ore is a true carbonate of iron, some of it yielding from 25 to 40 per cent. A small blast-furnace has been erected at Stanhope, where a very important and interesting experiment has been made, and a successful result obtained, in which this rider ironstone has been smelted, and pig-iron of a strong and excellent quality produced. This ore, even after being ground and washed, still contains some particles of *galena*, and which in smelting gives out at the furnace-top a heavy cloud of sulphurous smoke, of a forbidding aspect. The pig-iron, however, when remelted, yields no smoke from its surface, which would be the case if a small quantity of metallic lead were thrown in, from which it may be inferred that the lead is in the process of smelting entirely dissipated and driven off. What effect may be produced upon the conversion of this iron into bar-iron remains to be determined. The result of this experiment has been deemed so satisfactory as to induce the company to erect large smelting-works about three miles from Wolsingham. These works consist of two powerful blast-engines and six large blast-furnaces. In this enterprise we shall by and by behold the spoil of ancient mines, which has reposed for ages, brought to light, no longer as a useless, but as a useful material for the production of the common and ordinary sorts of pig-iron. Great and beneficial results are calculated upon, and should they be realized, will no doubt contribute greatly to the produce of our iron manufacture."

Other authorities do not speak so hopefully of this discovery, and certain it is, that of the six blast-furnaces of which Mr. Mushet speaks, only three have hitherto been erected, and only one of these is lighted. A great part of the furnaces now existing in Durham are chiefly employed in reducing ores procured from Whitby and from Scotland, and occasionally small quantities of hematite ore are procured from Devonshire and from Cumberland. There is a considerable quantity of ironstone of the argillaceous kind in the eastern division of Durham, but it is for the most part found at inaccessible depths, or in such positions of dislocation as to render the cost of working it too great. At a place called Shottley-bridge, about fifteen miles west of Newcastle, where the ore is plentiful and very accessible, there have been eight furnaces at work for some time, and six others are now about to be lighted. The argillaceous ironstone found at that place resembles in quality the ironstone of Staffordshire. This is the only portion of the county of Durham in which it has hitherto been found practicable to make iron in any large quantity with materials wholly found on the spot. I have a list of twenty-two furnaces now in blast in the two counties of Durham and Northumberland yielding weekly 1895 tons of pig-iron, equal to a yearly production of 94,750 tons, the quantity made in 1843 having been estimated at 25,750 tons, and in 1844 to only 21,250 tons. In various localities in Northumberland there is abundance of clay-ironstone in the immediate vicinity of plenty of excellent coal and limestone, and in the course of years large quantities of iron may be made in that district. The great obstacle to any sudden increase there and elsewhere is offered, as already mentioned, by the difficulty of procuring skilled labour. Any addition to the number of coal-miners can

be made only by slow degrees, and the same condition applies to all other classes of persons whose labour is required for the manufacture of iron. It is hopeless to stimulate the exertions of the persons already employed. They are naturally ready enough to exact higher rates of wages when the demand for their labour becomes more urgent, but succeeding in this they prefer to obtain the same amount of earnings, with higher rates of wages, to the securing of greater gains by the exertion of even the same amount of toil, so that a greater urgency in the demand may be, and frequently is, accompanied by a lessened production.

Under these circumstances, how the enormous demand existing and to arise from carrying out the railway schemes already sanctioned is to be met, it would be most difficult to say. The laying down of these lines and providing them with the needful working stock of carriages, &c. would absorb all the iron which it is reasonable to expect will be made in Great Britain during the next three years, and it affords no satisfactory solution of this difficulty to say that the quantity required will only be called for progressively, and that the demand will be spread over the same three years. To render this circumstance effective, we should be assured that no further projects will be sanctioned during the time spent in their construction, an assurance for which we can hardly look, and even then we should be left without a ton of iron applicable to the thousand other purposes for which this metal is so indispensable. If the difficulty presented by the want of labour could be surmounted, there appears no rational ground for supposing that we should, for a very long time to come, experience any deficiency in the means for making iron. In the anthracite coal district of South Wales, where clay-ironstone is thickly interstratified with the coal seams, there appears to be no reason to doubt that if the means employed in the anthracite district of America for smelting the clay-ironstone were adopted, it would prove equally successful. The difficulty consists in the sluggish nature of anthracite, which requires a more rapid draught than can be provided by the ordinary means of bellows and tall chimneys; and this is overcome in America by obtaining a great volume of air by means of *fanners*. The iron made with raw anthracite coals has been found by Mr. Mushet to be much stronger than iron made with coke, and after a variety of experiments, the earlier of which afforded but small encouragement, this fuel has been adopted by the proprietors of twenty-three furnaces, who avail themselves of only the ordinary means for providing a blast. The manner in which the railway demand has already limited other uses of iron, may be gathered from the following extract from a letter of recent date written to me by Mr. Mushet:—

"At the above period (1840) merchant bar-iron, boiler-plate, sheet-iron and rod-iron, principally occupied our mills; but these of late, particularly in South Wales, have given way in a great measure to the manufacture of railway bars, so as to eclipse in a striking manner the varied and extensive assortments required by the merchants' demands." The long period of dulness that intervened between 1839 and the beginning of 1845, accompanied as it was by a continued fall in the market price of iron, caused this metal to be applied, most advantageously, to a variety of new purposes, from which it will be prejudicial henceforth to withdraw it. In a well-known mercantile circular letter issued in February 1845 by Messrs. Jevons of Liverpool, it is stated that there had arisen "a new and increasing demand for iron roofs, iron houses, and fire-proof buildings in Liverpool," and that during the year then just passed upwards of 20,000 tons of cast and wrought iron had been so used in that town. These gentlemen further stated that preparations were going forward for the erection of still more extensive ranges of buildings of

similar construction during 1845, and that the sailing-ships and steam-vessels then under construction in that port would require 25,000 tons of plate-iron and angle-iron.

The employment of iron for the purpose last mentioned, that of ship-building, has already been an object of very great national importance. The extent to which this use for the metal may be carried in future years it is not possible to foresee, but we may base upon even our present limited experience the hope that by this means our furnaces and forges may be provided with some employment when our system of railways shall be completed. The tonnage of mercantile shipping belonging to the British empire in 1845 was 3,714,061 tons, and exceeded the amount in existence in 1814 by 1,097,096 tons, but during that interval there were built and registered ships amounting in their measurement to 5,476,957 tons, so that there were required to be built ships of the aggregate burthen of 4,379,861 tons, in order to repair the waste occasioned by wear and tear and by losses: altogether the building of ships has gone forward at the average rate of 176,676 tons yearly. Assuming for the moment that this same rate of building will be called for in future years, and that the whole of the mercantile shipping constructed would be built of iron, this would prove a very insufficient substitute for the demand now existing for railway purposes. I have before me a statement of the weight of iron used in building eight large sea-going steam-vessels, the aggregate measurement of which was 5922 tons, by which it is shown that the metal used was 2877 tons weight, or 9 cwt. 2 qrs. 24 lbs. for each ton of measurement, and at this rate the construction of 176,676 tons of shipping in each year would provide a market for no more than 85,814 tons of wrought iron, equal to 115,849 tons of pig-iron. We cannot suppose, however great may be the advantages attendant upon the substitution of iron for timber in ship-building, that this use of the latter material will be all at once, or indeed for many years, abandoned. There are many existing interests opposed to the change, and there is much of prejudice still to be overcome before all our merchant-ships will be built of iron. We must likewise bear in mind the now well-established fact, that iron ships are far more durable than those built of timber, that they require much less repair, and that they are less subject to accident and to loss. It cannot be necessary, however, to enlarge upon this subject, since the Association has already been favoured by Mr. Fairbairn at one of its former meetings—that held at Glasgow in 1840—with a valuable paper upon the subject.

Placing this subject in another point of view, may we not however feel justified in believing, that when opposing interests shall have been silenced, and existing prejudices shall be overcome, and the fast increasing commerce of this country shall have experienced some degree of that development which is expected to spring from late changes in our commercial legislation, the rate of increase hitherto sufficient to supply the waste of our mercantile marine, and to provide what has been necessary for its increase, will no longer suffice to that end, and that although our iron ships may outlast by three or four times the less durable vessels now constructed, and through all their existence may call for little or no materials to be used for their repair, that the necessity for additional shipping may in great part prove an equivalent for the lessened demand otherwise arising?

The building of iron ships is at this time proceeding at a greater rate than at any previous moment since their first introduction, although the price of iron has so materially advanced, and this should give us the assurance that when, as we may expect it will happen, the falling off of railway demand, or the exertions of our iron-masters, shall have restored the equilibrium between

supply and demand, and the price shall again have become more moderate, an impetus will be given to the production of shipping, not alone for the uses of our own merchants, but for carrying on the trade and navigation of other countries. The cost of our shipping will then be so materially reduced, both their first cost and the expense of their maintenance, that the objection so often and unfortunately so successfully offered by our shipowners to any relaxations in our commercial code affecting their business, that the greater cheapness with which shipping can be produced in foreign countries prevents their successfully competing with ships of those countries, can no longer be urged with any plausibility; but on the contrary, that ships of English construction will then be the cheapest in the world. It has been said that fluctuations in the price of iron do not cause any considerable difference in the cost of iron vessels, so large a proportion of their whole cost consisting in labour. A reduction of 20*s.* per ton in the price of the material will, however, cause an œconomy of 10*s.* per measurement ton in the cost of the ship, and it will hardly be said that the very possible rise or fall of 3*l.* or 4*l.* per ton in the price of iron plates is an immaterial circumstance to the shipbuilder. But the cheapness here spoken of will no doubt be principally found in the greater durability and the insignificant cost of repairs of metal ships.

A statement was inserted a few months ago in a Scotch newspaper, giving the particulars of the iron ships then under construction in the Clyde; they amounted to twenty-four in number, and were of the aggregate burthen of 14,032 tons (see Appendix No. 8). These were all steam-vessels, to which class of shipping iron has hitherto been principally applied, although there is no reason for supposing that it is not equally applicable to every description of naval architecture. The reason for this circumstance may probably be found in the fact, that the construction and employment of steam-vessels has, for the most part, been undertaken by persons not previously interested in shipping, and who consequently had no prejudice or habit to overcome in their choice of material.

This statement, imperfect as it necessarily is, would be more glaringly so if it did not present some particulars of our external iron trade.

So recently as the beginning of the present century more than two-fifths of all the iron used in this kingdom was imported from the north of Europe. Foreign metal was then used for very many of the purposes to which iron was at that time generally applied in England, and it was so used indiscriminately with British iron. In 1806 the use of foreign iron had been lessened by nearly one-third, while the home production was so increased as to form seven-eighths of the quantity used. In a few years after our make was beyond our own wants, and foreign iron ceased to be imported for any purposes to which the produce of our own forges could be applied. Thenceforward our demands have been confined to metal of the qualities from which alone steel can be made. Our exports of British iron have, on the contrary, increased progressively, and have now become an object of great national importance. The statement given in the Appendix, No. 9 shows the yearly progress of the trade since 1827 up to the year 1845 inclusive. It will be seen on consulting this statement, that the quantity had increased from 92,313 tons in 1827 to 351,978 tons in 1845, and that the declared value of the shipments advanced in that interval from £1,215,561 to £3,501,895. A column has been added to the table, exhibiting the average value per ton of all forms of iron exported in each year, from which it will be seen how great an influence price has, in its advance and its diminution, upon the lessening or increase of our exports. In 1840, when the average value appears to have

been 9*l.* 8*s.* 2*d.*, the quantity of British iron exported was 268,328 tons. The price in the following years fell rapidly, and the demands from other countries increased as rapidly. In 1843, when the average price is represented by 5*l.* 15*s.* 5*d.* per ton, the exports were 448,925 tons. In 1844 the quantity was slightly increased, viz. to 458,745 tons, although the price had advanced to 6*l.* 19*s.* 2*d.* per ton; but in 1845, the further advance in the average declared value to 9*l.* 18*s.* 11*d.* per ton, reduced our foreign shipments to 351,978 tons, or by more than 23 per cent.

It is worthy of remark, that we now export largely, more largely than in former periods we ever imported from the same quarter, iron in its crude state, and articles manufactured with the same, to the countries whence we once drew the largest proportion of what was used by us. In 1844 our shipments of iron, in its various forms, to the north of Europe amounted to 178,635 tons, equal probably to 200,000 tons of pig-iron; and in 1845, notwithstanding the great speculative demand and rise in price at home, our shipments amounted to 140,006 tons, equal probably to 160,000 of pig-iron. In those two years the whole of our colonies and dependencies took from us, in 1844, 78,594 tons; and in 1845, 60,683 tons.

Our largest customers are found in the United States of America, and it is probable that they will long continue to be so, unless the citizens of those states in which materials for producing iron are found should be unduly stimulated to increase their home production through the existence of high prices in this country. An increased demand from that quarter is expected when the more liberal tariff recently passed at Washington shall come into operation, but it is clear that the realising of that expectation must depend greatly upon the state of markets in this country (see Appendix, No. 11).

A writer of the protectionist school, in an article inserted in the 'National Magazine,' published in New York in July 1845, states that the make of iron in the United States in that year from 540 blast-furnaces would amount to 486,000 tons, and that the domestic supply would ere long be brought to meet the entire wants of the country. New furnaces and rolling-mills are, according to this writer, being erected in every direction, and those works that had been inoperative and unproductive, from the low prices of iron in 1843 and 1844, were again at work, so that it might soon be unnecessary to import a ton of the metal from Europe. With a moderate price in England we need not put much faith in this assertion, which was put forth as an inducement to Congress to add to the high protection then afforded by the tariff, but which is now reduced.

France, notwithstanding the exorbitant duties charged on importation, takes from us a considerable and constantly increasing quantity of this metal (see Appendix, No. 12), and although the production of pig-iron in that country has increased from about 220,000 tons in 1831 to about 420,000 tons in 1843, and is still increasing, the want of a sufficient supply of this all-important metal is severely felt in that country, and the high price is found to weigh grievously upon various branches of industry. In particular a cry has been raised, which it is expected may be successful, in favour of the admission, free of duty, of plate-iron suitable for ship-building, but the eagerness now shown to obtain this concession will be much abated should the price of the material advance in any great degree in England. At this time we are certainly not in any condition to meet the demand that might come upon us should that concession be made by the French Chambers.

With the exception of England, Sweden appears to be the only country which has or can be expected to have any disposable quantity of iron for exportation, and it does not seem likely that we shall be a customer for any, except

that which we need for converting into steel, to which use Swedish iron is peculiarly applicable, and for which its high price causes it to be reserved. To Russia our shipments of this metal are fully equal to the quantity imported thence.

After much consideration given to the circumstances in which our iron manufacture is now placed, and to its prospects for the future, I venture, with some hesitation, to offer the following opinion.

Legislative sanction has been given in this and the two preceding years to the construction of many thousand miles of new railways, in the completion of which so many interests are engaged, that we must not expect any considerable portion of them to be abandoned by their projectors. We must for this reason expect that for some few years to come, during which these works will be going forward, the price of iron will be high. The tendency of this high price will be, to give an impetus to the manufacture, and to cause much new capital to be invested for its extension, for which ample opportunity presents itself in different localities, although in other places, as in Staffordshire, where the manufacture has hitherto flourished, there is more reason to expect diminution than increase, owing to a failure in the supply of materials. The great obstacle to the forming of new establishments, and to the extension of those already in operation, consists in the difficulty of procuring the necessary amount of labour, miners, furnace-men and others. This obstacle will, however, be gradually and progressively lessened, and when the present exaggerated railway demand shall have ceased, as it must necessarily do through the completion of the lines which alone can be profitably opened, and the demand thence arising for iron shall be limited to the quantity—still, however, considerable—which will be needed for keeping the lines in repair (see App. No. 13), we shall find ourselves in possession of means for making iron much beyond what have at any previous time existed, and very greatly beyond any probable demand to arise from other and existing channels of employment at home, or from foreign countries. The price will consequently fall, as it has done at former times and under analogous circumstances. We shall then find that this metal will again be employed in uses from which it may have been excluded by the previous high price. From the improvements already made, and from others which we may expect will be introduced into the processes of manufacture, we may even find that the market price will fall to a lower point than has hitherto been witnessed, and new uses may in consequence be discovered whereto to apply this metal. All this, however, must be the work of time, and it seems but too probable that in the meanwhile our iron-masters will have to undergo a somewhat lengthened season of adversity, for the enduring of which they are in a measure prepared by former experience.

Appendix No. 1.

Manufacture of Pig-iron in England and Wales, 1788.

Made with coke of pit-coal.

Counties.	No. of Furnaces.	Tons of Iron.	
Shropshire	21	23,100	
Staffordshire	9	6,900	
Derbyshire	7	4,200	
Yorkshire	6	4,500	
Cumberland	1	700	
Cheshire	1	600	
Glamorganshire	6	6,600	
Brecknockshire	2	1,600	
			48,200

Made with wood-charcoal.

Gloucestershire	4	2,600	
Monmouthshire	3	2,100	
Glamorganshire	3	1,800	
Carmarthenshire	1	400	
Merionethshire	1	400	
Shropshire	3	1,800	
Derbyshire	1	300	
Yorkshire	1	600	
Westmoreland	1	400	
Cumberland	1	300	
Lancashire	3	2,100	
Sussex	2	300	
			13,100
Total			61,300

Appendix No. 2.

Manufacture of Iron in Great Britain in 1796.

Counties.	No. of Furnaces.	Tons of Iron.
Chester	2	1,958
Cumberland	4	2,034
Derbyshire	3	2,107
Gloucestershire	2	380
Herefordshire	5	2,529
Lincolnshire	2	705
Shropshire	23	32,969
Sussex	1	173
South Wales	25	34,251
North Wales	3	1,434
Staffordshire	14	13,211
Yorkshire	20	17,242
	104	108,993
Scotland	17	16,086
Total—Great Britain	121	125,079

Appendix No. 3.

Production of Iron in 1806 in Great Britain.

Counties.	No. of Furnaces.	Tons of Pig-iron.
Cumberland	4	1,491
Derbyshire	12	10,329
Gloucestershire	2	1,629
Lancashire	2	2,500
Monmouthshire	3	2,444
Shropshire	28	54,966
Staffordshire	31	49,460
Yorkshire	23	26,671
South Wales	36	75,601
North Wales	3	2,075
Old charcoal furnaces in different counties	11	7,800
Total—England and Wales	155	234,966
Scotland	18	23,240
Total—Great Britain	173	258,206

Appendix No. 4.

Production of Iron in Great Britain in 1823.

Counties.	No. of Furnaces.	Tons of Pig-iron.
Staffordshire	84	133,590
Shropshire	38	57,923
Yorkshire	26	27,311
Derbyshire	15	14,038
Northumberland and Durham	2	2,379
South Wales	72	182,325
North Wales (estimated)	...	10,000
	237	427,566
Scotland	22	24,500
Total—Great Britain	259	452,066

Appendix No. 5.

Production of Iron in Great Britain in 1830.

Counties.	No. of Furnaces.	Tons of Pig-iron.
Staffordshire	123	212,604
Shropshire	48	73,418
Yorkshire	27	28,926
Derbyshire	18	17,999
Northumberland and Durham	4	5,327
South Wales	113	277,643
North Wales (estimated)	...	25,000
	333	640,917
Scotland	27	37,500
Total—Great Britain	360	678,417

Appendix No. 6.

Quantity of Iron made in Great Britain in 1839, as stated by David Mushet, Esq.

Districts.	No. of Furnaces.	Tons of Pig-iron.
South Wales	122	453,880
Forest of Dean	5	18,200
Shropshire	29	80,940
Staffordshire (South)	106	346,213
Staffordshire (North)	7	18,200
North Wales	13	33,800
Derbyshire	14	34,372
Yorkshire	22	52,416
Northumberland and Durham	5	13,000
Scotland	54	196,960
	377	1,247,981
Lancashire (charcoal-iron)		800
Total of pig-iron in Great Britain		1,248,781

Appendix No. 7.

Production of Iron in Great Britain in the year 1840, as ascertained by Mr. William Jessop, of the Butterley Iron Works, Derbyshire.

Districts.	Number of Furnaces		Iron made.	Coal used.
	In blast.	Out of blast.		
			tons.	tons.
Forest of Dean	4	...	15,500	60,000
South Wales	132	31	505,000	1,436,000
North Wales	12	3	26,500	110,000
Northumberland	5	1	11,000	38,500
Yorkshire	25	7	56,000	306,500
Derbyshire	13	5	31,000	129,000
North Staffordshire	7	9	20,500	83,000
South Staffordshire	116	19	407,150	1,582,000
Shropshire	24	7	82,750	409,000
Scotland	64	6	241,000	723,000
	402	88	1,396,400	4,877,000
Coal used in converting to wrought-iron				2,000,000
				6,877,000

Of the above 402 furnaces, there were using hot air, 162; cold air, 240.

Appendix No. 8.

Iron Steam-Vessels being built in the Clyde during the Spring of 1846.

1	of	2,000	tons burthen and 750 horse-power.
1	...	1,300	 520
1	...	1,225	 450
1	...	1,100	 400
1	...	900	 400
1	...	800	 400
1	...	700	 280
1	...	600	 300
1	...	600	 220
1	...	600	 300
1	...	500	 200
1	...	450	 250
1	...	450	 250
1	...	450	 150
1	...	346	 50
1	...	346	 50
1	...	300	 160
1	...	275	 35
1	...	275	 35
1	...	275	 35
1	...	150	 120
1	...	150	 100
1	...	120	 65
1	...	120	 60
24		14,032	5,580

Appendix No. 9.

Quantities of British Iron exported, with the declared value of the same, and the average value of each ton exported in each year from 1827 to 1845 inclusive, stated in tons.

Years.	Bar-iron.	Pig-iron.	Castings.	All kinds*.	Declared value.	Average declared value per ton.
					£	£. s. d.
1827.	45,284	7,095	6,292	92,313	1,215,561	13 3 5
1828.	51,108	7,826	6,205	100,403	1,226,617	12 4 4
1829.	56,178	8,931	8,219	108,275	1,162,931	10 14 9
1830.	59,885	12,036	8,854	117,420	1,078,523	9 3 8
1831.	64,012	12,444	10,361	124,312	1,123,372	9 0 8
1832.	74,024	17,566	12,495	147,636	1,190,749	8 1 3
1833.	75,333	22,988	14,763	162,815	1,405,035	8 12 7
1834.	70,809	21,788	13,870	158,166	1,406,872	8 17 10
1835.	107,715	33,073	12,604	199,007	1,643,741	8 5 2
1836.	97,762	33,880	19,891	192,352	2,342,674	12 3 7
1837.	95,663	44,387	12,373	194,292	2,009,259	10 6 10
1838.	141,923	48,554	14,942	256,017	2,535,692	9 18 1
1839.	136,452	43,460	10,836	247,912	2,719,824	10 19 6
1840.	144,719	49,801	9,886	268,328	2,524,859	9 8 2
1841.	189,249	85,866	14,077	360,875	2,877,278	7 19 5
1842.	191,301	93,851	15,934	369,398	2,457,717	6 13 0
1843.	198,774	154,770	16,500	448,925	2,590,833	5 15 5
1844.	249,915	99,960	18,969	458,745	3,193,368	6 19 2
1845.	153,813	77,362	22,036	351,978	3,501,895	9 18 11

* Including the kinds stated in the previous columns, together with bolt- and rod-iron, iron-wire, anchors, grapnels, &c., hoops, nails, and all other sorts not included in the foregoing.

Appendix No. 10.

Make of Iron in 1843 compared with 1840.

	1840.	1843.	Decrease.	Increase.
	tons.	tons.	tons.	tons.
Forest of Dean	15,500	8,000	7,500	
South Wales	505,000	457,355	47,650	
North Wales	26,500	19,750	6,750	
Northumberland	11,000	25,750	.....	14,750
Yorkshire	56,000	42,000	14,000	
Derbyshire	31,000	25,750	5,250	
North Staffordshire	20,500	21,750	.....	1,250
South Staffordshire	407,150	300,250	106,900	
Shropshire	82,750	76,200	6,550	
Scotland	241,000	238,550	2,450	
	1,396,400	1,215,350	197,050	16,000
	1,215,350	.....	16,000	
Less in 1843	181,050	.....	181,050	

Appendix No. 11.

Quantity and declared Value of Iron, wrought and unwrought, exported to the United States of America in each year from 1831 to 1844.

Years.	Tons.	Value.	Years.	Tons.	Value.
1831.	30,818	£248,707	1838.	71,235	£634,395
1832.	37,565	284,502	1839.	74,772	801,198
1833.	54,124	412,515	1840.	38,603	355,534
1834.	40,625	322,156	1841.	79,186	626,532
1835.	51,951	408,368	1842.	58,418	394,854
1836.	79,330	612,387	1843.	31,909	223,668
1837.	49,204	489,309	1844.	107,379	696,937

Appendix No. 12.

Quantity and declared Value of Iron exported to France in each year from 1831 to 1844.

Years.	Tons.	Value.	Years.	Tons.	Value.
1831.	2,721	£ 21,416	1838.	15,723	£103,026
1832.	5,657	32,768	1839.	14,288	93,356
1833.	7,424	41,696	1840.	16,804	88,631
1834.	8,306	55,060	1841.	19,099	95,943
1835.	14,863	82,302	1842.	23,428	105,172
1836.	14,016	115,718	1843.	29,626	120,220
1837.	15,015	96,415	1844.	21,352	100,982

Appendix No. 13.

Estimated quantity of Iron required for the construction and putting into operation each mile of Railway.

	Tons per mile.		Tons of Pig-iron.
Rails, 75 lbs. per yard	235	equal to	317½
Chairs, 40 lbs. each	125	.....	125
Locomotive engines, 1 per mile	25	.....	33⅓
Wagons and carriages, iron-work	25	.....	33⅓
Tanks, &c.	5	.....	5
Turntables, points and sidings.....	100	.....	110
Workshops	30	.....	40½
Coke, ovens and sundries.....	5	.....	5
Bridges, roofs, stations, &c.	30	.....	40½
			711

Required to maintain the above, each year—

Rails, chairs, locomotives, turntables, &c., 50 tons of wrought- and cast-iron, equal, each year, to 61 tons of pig-iron.

N.B. The above estimate has been furnished by an experienced railway engineer to the chairman of a railway company. The quantities are greater than are commonly assigned, but an abatement of 25 per cent. would not disturb the calculation made by me (page 109); and when provision is made for maintaining in repair the railways now open, it would absorb all the iron which will probably be made in the next four years, to construct, at that abatement of 25 per cent., the lines now sanctioned by Parliament.

Third Report on Atmospheric Waves.
By William Radcliff Birt.

The two former Reports which I have had the honour to present to the Association necessarily possessed a fragmentary character. Sir John Herschel, in his Report on Meteorological Reductions (1843), distinctly traced two well-defined atmospheric waves which passed over the British Isles and the west of Europe, one in September 1836, the other in December 1837. These may be regarded as the earliest instances of our detecting and clearly apprehending the character of the atmospheric undulations constantly traversing our oceans and continents, and mark the commencement of that æra in atmospheric research to which Mr. Forbes alluded in his Report on the Recent Progress and Present State of Meteorology, presented to the Association in 1832, when he said, "The great extent of country over which the accidental variations of the barometer take place, is one of their most striking features; and in a future and more advanced state of meteorology we may be able to draw the most interesting and important conclusions from the great atmospheric tidal waves which are thus perpetually traversing oceans and continents."

Sir John Herschel, in the conclusion of the report to which allusion has been made, noticed the larger fluctuations which I had observed in the autumn of 1842, especially the symmetrical wave which occupied thirteen days in November for its complete rise and fall. The curves representing these larger undulations were appended to Sir John Herschel's report; and the Association, under the direction of the Magnetical Committee and the immediate superintendence of Sir John, entrusted me with the further in-

vestigation of these waves, especially that of November. The mode of investigation and the partial results arrived at during the period between the sittings of the Association in 1843 and 1844 form the subject of my first report, which, as before stated, must be regarded only as a fragment.

During the further investigation of the wave of November various observations came to hand, which appeared to throw considerable light on the general character of atmospheric undulations. The publication of the Greenwich and Toronto observations afforded an interesting comparison of the passages of certain maxima at these distant stations, and by extending this comparison to Prague and Munich, several interesting features of certain secondary waves during the transit of a supposed normal wave appeared so clearly to be made out, that it was deemed desirable to include the whole of this comparison in the succeeding report, rather than run the risk of its being lost by deferring it until after the examination of the great wave should be completed. Another most interesting result arrived at about this time, was the recurrence of the great wave of November. The return of this interesting phænomenon appeared so strikingly distinct in 1843 and 1844, that to have omitted noticing it in the Report would have greatly contributed to retard the inquiry. It accordingly forms the second section of the Report of 1845. These circumstances, with the further investigation of the great wave of November 1842, give to the second report a more fragmentary character.

Previous to entering on the immediate subject of the present report, it will be desirable to review the steps that have been taken for observing the great symmetrical wave on its return in 1845; and also to notice any other circumstance that may have transpired during the past year at all calculated to throw any light on the subject of our investigations. With regard to the first point, certain instructions were drawn up, which were forwarded to gentlemen interested in meteorological research, and otherwise circulated, in consequence of which a number of interesting and valuable observations were obtained. The results of the examination of these observations, as far as it has yet proceeded, will form the first part of the present report. In the Philosophical Magazine for April in the present year Mr. Brown published a voluminous paper on the oscillations of the barometer, with particular reference to the meteorological phænomena of November 1842, the month in which I first observed the great symmetrical wave. This paper is accompanied by diagrams representing the direction of the wind in England, Scotland and Ireland every day, from the 1st to the 26th inclusive. Upon a very careful perusal of it, I found that the observations, as given in the diagrams, very beautifully illustrated Prof. Dove's theory of parallel currents or alternately disposed beds of oppositely directed winds, and appeared to throw so clear a light on the real character of the atmospheric undulations, that I was induced to enter upon a very careful examination of the barometric observations in connexion with the diagrams of the wind. The result of this examination has been to give the inquiry a completeness which it was before destitute of. It was previously difficult to define the real notion we formed of an atmospheric wave; not so much from the distribution of pressure over a tract of country gradually decreasing on each side a line of maxima, as from the relation of the aërial currents or winds to this distribution of pressure of which we were to a certain extent ignorant. The examination of these observations has exhibited very clearly the distribution of the aërial currents in relation to the distribution of pressure, and enabled us to define the nature of an atmospheric wave both as regards its undulatory and molecular motion. This definition, with the examination of the observations, forms the second part of this report.

Part I.—Recurrence of Symmetrical Wave.

The following were the instructions drawn up for observing the Great Symmetrical Wave on its return in 1845.

"The recurrence of the great November Wave observed in 1842 (an engraving of which is inserted in the Report of the Thirteenth Meeting of the British Association for the Advancement of Science), during the autumns of 1843 and 1844, renders the barometric movements of the months of October and November highly interesting. It is accordingly proposed that meteorological observations, on a similar plan, should be made as extensively as possible, with a view to observe this particular wave; and meteorologists are invited to direct their particular attention to the oscillations of the barometer during the months above-named.

"Times of Observation.

"The following hours are the most suitable for the object now in view: 3 A.M., 9 A.M., 3 P.M. and 9 P.M.; these hours divide the day into four equal parts; they have been recommended by the Royal Society as *meteorological* hours, and are the hours at which observations are made daily, by direction and under the superintendence of the Honourable the Corporation of the Trinity House, which have been most advantageously used in the examination of atmospheric waves.

"In cases, however, in which the observation at 3 A.M. may be inconvenient or impracticable, it will be important to substitute for it *two* observations, one at midnight and the other at 6 in the morning, so that the hours of observation will in such cases be 6 A.M., 9 A.M., 3 P.M., 9 P.M. and midnight.

"To individuals who cannot command these hours, it is recommended that observations should be made *as near them as possible*; these will still be valuable, although not to so great an extent as those made at the regular hours. In these cases, however, it will be absolutely necessary to substitute *two* readings for every one of the regular hours omitted—one previous to, the other succeeding the hour so omitted; and these should, if possible, include an equal interval both before and after such hour. In all cases the *exact* hour and minute of mean time at the place of observation should be inserted in its appropriate column in the form sent herewith.

"At the regular hours of observation, or any others that the observer may fix upon, in accordance with the foregoing instructions, it will be necessary to observe,

"1st. The barometer, with its attached thermometer, and enter in the form the *actual* height observed with the temperature of the mercury.

"2nd. The external and dry thermometer.

"3rd. The wet bulb thermometer.

"[These observations are particularly essential in order to separate the pressure of the vapour from the aggregate pressure, as measured by the mercurial column.]

"4th. The direction and force of the wind.

"[These are important to determine the connexion between the undulatory and molecular motion of the wave.]

"5th. The character of the weather at the times of observation; which may be recorded by Capt. Beaufort's symbols.

"It is proposed to commence the observations on the 1st of October next, and continue them *daily* until the end of November, unless it should be found that at that time the Wave is not completed, in which case it will be requisite to continue them a few days longer.

"It will be necessary, on returning the form when filled, to accompany it

with the following data for reduction. A blank is left for this purpose on the back of the form.

"The geographical co-ordinates of the place of observation, viz. latitude and longitude.

"The altitude of the cistern of the barometer above the level of the sea, *exactly*; if not, as near as it can be obtained.

"The internal diameter of the tube of the barometer.

"The capacity, neutral point, and temperature.

"[These are usually engraved on the instrument.]

"If the co-efficients of the diurnal and annual oscillations have been determined for the place of observation, include them.

"Those sets of observations which may be reduced by the observers, should be accompanied with the original observations, and a reference to the tables used in their reduction, also the data above-mentioned.

"All observations that may be made in accordance with these instructions and forwarded to me, will be carefully examined and reported on at the next meeting of the British Association. "W. R. BIRT."

"*2 Sidney Place, Cambridge Road, Bethnal Green.*"

In accordance with these instructions observations were received from the following stations and observers.

TABLE I.

Station.	Vessel or Establishment.	Observer or Authority.
Sandwick Manse, Orkneys		Rev. Charles Clouston.
West coast of Scotland	H.M.S.V. "Shearwater"	Commander C. G. Robinson.
East coast of Great Britain	H.M. Ketch "Sparrow"	William Turton, R.N.
Firth of Forth	H.M.S.V. "Mastiff"	The Officers.
Longstone, Northumberland	Lighthouse	William Darling.
Newcastle-upon-Tyne	Philosophical Society	George Muras, Esq.
Belfast, Ireland		Dr. Stevelly.
Stokesley, Yorkshire		John Call, Esq.
Markree, Ireland		Edward J. Cooper, Esq., M.P.
York		John Phillips, Esq., F.R.S.
Heligoland	Lighthouse.	
Galway, Ireland		Lieut. Sidney, R.N.
Lough Corrib and Galway		Lieut. Beechey, R.N.
Portarlington, Ireland		M. Hanlon, M.B.
Dublin, Ireland	Ordnance Survey Office.	Capt. Larcom, R.E.
Limerick, Ireland		R. T. Maunsell, Esq.
Bardsey Island off Wales	Lighthouse.	
Birmingham	Philosophical Institution	William Onion, Esq.
Haisboro', Norfolk	Lighthouse.	
Coast of Suffolk	H.M.S.V. "Blazer"	Capt. Owen Stanly, R.N.
South of Ireland	H.M.S.V. "Lucifer"	Commander G. A. Frazer.
South of Ireland	H.M.S.V. "Tartarus"	Commander James Wolfe.
South Bishop off Wales	Lighthouse.	
Pembroke	H.M.S.V. "Firefly"	Capt. Beechey, R.N.
Gloucester		John Jones, Esq.
Harwich	H.M.S.V. "Porcupine".	The Officers.
London		W. R. Birt.
Ramsgate	H.M.S.V. "Porcupine".	The Officers.
Scilly Isles	Lighthouse	E. L. Davis.
Helston, Cornwall		M. P. Moyle, Esq.
Portsmouth		Commander W. L. Sheringham, [R.N.
St. Catherine's Point, I. of Wight	Lighthouse.	
Hastings		Sir Howard Elphinstone, Bart.
St. Helier's, Jersey		Capt. Childers.

N.B. I am indebted to the Honorable the Corporation of the Trinity House for the Light-

house observations, and to Rear-Admiral Beaufort, R.N., for the observations made on board the surveying vessels.—W. R. B.

These observations, which were principally undertaken with a view to observe the return of the great wave, have been attended with highly interesting results. I shall first notice the result of the comparison of the observations at this station (Cambridge Heath) with those made at Leicester Square in 1842, as fully establishing not only the return of the great wave, but also that of other extensive undulations.

Section I.—Comparison of observations made at Cambridge Heath (north-east of London) from Oct. 1, 1845 to Nov. 21, 1845, with observations made at Leicester Square from Sept. 14, 1842 to Nov. 25, 1842.

The observations of 1842 are projected in curves and appended to Sir John Herschel's 'Report on Meteorological Reductions,' 1843.

1842. I. Plate I. fig. 1 (Report 1843) exhibits an undulation consisting of a gentle barometric fall and almost as gentle a rise during seventeen days, namely from Sept. 14 to Oct. 1, interrupted only by the diurnal oscillations, which are in general well-developed.

1845. In 1845 this undulation of seventeen days' interval returned. It was observed from Oct. 1 (the commencement of the observations) to the 19th, but instead of exhibiting the gentle fall and ascent noticed in 1842, it was interrupted by two most remarkable superposed waves. The first occurred on the 4th, 5th, and 6th of October, and the second from the 11th to the 16th.

When these waves (the commencement and termination of each being well-marked) are abstracted from the general curve, the resemblance between the curves of 1842 and 1845 is very apparent.

1842. September 14 to October 1.
1845. October 1 to October 19.

II. The curves of the succeeding four days in the two periods 1842 and 1845 exhibit similar barometric fluctuations, so that the movements during the four days succeeding the seventeen-day wave in 1845 are identical with those of the four days succeeding the same wave in 1842.

1842. October 2 to 5
1845. October 19 to 22
} both inclusive.

III. The exact identity between the curves of 1842 and 1845 breaks off on Oct. 23, 1845. The barometer maintains an elevation above thirty inches during the period in 1845 that the movements are not in accordance with those of 1842.

IV. Plate I, fig. 3 (Report 1843). The identity between the curves of 1842 and 1845 again commences on Oct. 27, 1845, and is maintained in a very close manner until midnight of Nov. 6.

1842. October 31, midnight to November 11, noon.
1845. October 27, noon to November 6, midnight.

V. In consequence of the movements from Oct. 27 to Nov. 6, 1845, exhibiting so close a similarity to those between Oct. 31 and Nov. 11 in 1842 which immediately preceded the great wave in that year, considerable expectation was raised that the great wave would set in on the morning of the 7th. At midnight of the 6th, the similarity between the curves that had been so closely maintained during ten days and a half began to fail, and rendered it difficult to determine for some days if the preceding movements had really been followed by the great wave. This question was set at rest as the observations proceeded; for on comparing the curve from the 6th to the 21st with that of the great wave of Nov. 1842 (Plate II., Report 1843), there was every

reason to believe that it had again returned and that its fourth transit had been observed. Between these epochs, Nov. 6 and 21, all its essential features were exhibited. The large central undulation, also forming the crown of the great wave and occupying in this instance five days, was very distinctly marked; and the two smaller undulations on each side the central wave, making with it the five of which the great wave is composed, were also well-developed. These smaller waves did not appear to co-ordinate with those of former transits. The great wave culminated on the 14th.

Corresponding barometric movements.

		Crest.
1842.	November 11 to November 25.	Nov. 18.
1843.	November 6 to November 21.	Nov. 14.
1844.	October 20 to November 4.	Oct. 27.
1845.	November 6 to November 21.	Nov. 14.

VI. The movements between the above epochs in each year were more or less symmetrical, the axes occurring on the dates indicating the passage of the crests. In the year 1845 the symmetrical movements appeared to extend greatly beyond the limits noticed above, for not only did the central undulation which culminated on the 14th form the axis of the great wave (properly so called), but also of a system *at least* double its extent, namely from Oct. 29 to Nov. 28. Observations received from Hastings appear to indicate that the barometric oscillations during October, November and December were symmetrical, the axis occurring about the middle of November.

VII. In my last report (Report, 1845, page 116) I stated that the minimum of the 16th of Feb. and that of the 5th of Oct. in the year 1841, formed the limits of the period of least range for that year. It is well known that the barometric oscillations are divisible into *two* classes; those of *small* range, confined to the *summer* half year; and those of *great* range, the period of their development being the *winter*. These greater oscillations begin to appear in October. Fig. 2, Plate I. (Report, 1843) exhibits a similar undulation to that of Sept. 14 to Oct. 1, 1842, of seventeen days' interval with *two* subordinate *maxima* interposed. The depression of the 23rd was very considerable, and rendered memorable by the inundation of the Madeiras. We accordingly find that the larger undulations began to appear in these latitudes in 1842, about the 16th of Oct. The seventeen-day undulation, Sept. 14 to Oct. 1, occurring about a fortnight later in 1845, brought it within the period of the commencement of the greater secondary undulations, and we find it interrupted by *two* very remarkable waves, in both cases rising above the general surface of the normal wave. On comparing the curve from Oct. 1 to 17, 1845, with that of Oct. 15 to 31, 1842, and bringing the minima in both cases on the same vertical line, but little if any resemblance can be traced between them. There are however these interesting exceptions. During the first seven and a half days the descent in each case is interrupted by a superposed wave, the co-ordinates of that of 1842, being about double those of the superposed wave of 1845. The ascent during the succeeding seven and a half days is also interrupted in each case by superposed waves, but the characters of them are reversed, the largest occurring in 1845 and the smallest in 1842; the relations are nearly similar to those characterizing the superposed waves of the descent, that of 1845 being nearly double that of 1842. Another most remarkable circumstance is also apparent on the comparison of these curves, the displacement of the maxima of these superposed waves, or the interval between their crests. It is probable that three waves transited during the seventeen-day undulation, Oct. 14 to 31, 1842, having their respective maxima on the 21st, 25th, and 27th; there are also traces of three

during the seventeen-day undulation of Oct. 1 to 19, 1845, having their respective maxima on the 5th, 10th, and 14th. Taking the same vertical ordinates in each curve, we have the epochs of the troughs of the first superposed waves nearly similar but separated by an interval of civil reckoning of fourteen and a half days; that is, the gentle undulation of the last half of September occurred a fortnight later, and the superposed waves indicating the disturbed state of the atmosphere, and characterizing the period of greater barometric oscillation, came rolling on a fortnight earlier; the two coinciding and producing the compound curve really observed. The first of these superposed waves being about half the size of the corresponding wave in 1842, passed its maximum about a day and a half earlier, and a small wave succeeding it brought the minimum on the same vertical line as that of 1842. In a similar manner the largest superposed wave in 1845 culminated at a later period of the normal wave than the smaller wave of 1842. In consequence of these different relations of the superposed waves of 1842 and 1845, the two apices were much nearer in 1842 than in 1845.

From these remarks it appears that, taking the barometric movements from Sept. 14, 1842 to Nov. 25 of the same year, containing two undulations of seventeen days' interval, and comparing them with those from Oct. 1 to Nov. 21 of 1845, only one undulation of seventeen days' interval was observed in the latter year, namely from Oct. 1 to 19; that this undulation was not of the gentle flowing character manifested by that from Sept. 14 to Oct. 1, 1842, but was interrupted by the same number of superposed waves as that from Oct. 14 to 31, 1842; and that this state of things was brought about by the later occurrence of the normal wave, and the earlier occurrence of the superposed waves. Of the two seventeen-day undulations of 1842 the first (Sept. 14 to Oct. 1) returned in 1845.

VIII. In addition to the absence of the second seventeen-day interval, Oct. 14 to 31, 1842, in the observations of 1845; the preceding movements, Oct. 6 to 13, 1842 (the barometer attaining a considerable altitude), were not observed in 1845.

IX. During the period from Oct. 1 to Nov. 21 in 1845, the barometric movements of Oct. 23 to 26 were the only oscillations that appeared to have no corresponding movements in 1842.

X. The distinctness with which the great wave commenced in 1842 and 1845, and the breaking off of the exact similarity between the curve of the preceding ten and a half days which had been so closely maintained just as the wave commenced in 1845, exhibit this interesting phænomenon in all its individuality, and completely separate it from all the preceding barometric movements.

XI. The individuality which is thus given to the great wave, the distinctness of its essential features, the close resemblance of its curves in 1842, 1843 and 1845, and the closer relations existing between those of 1842 and 1845, induce the strong belief that we have obtained the *type* of the barometric oscillations during the middle portion of November. This type I propose to express in the following language.

"That during fourteen days in November more or less equally disposed about the middle of the month, the oscillations of the barometer exhibit a remarkably symmetrical character, that is to say, the fall succeeding the transit of the maximum or highest reading, is to a great extent similar to the preceding rise. This rise and fall is not continuous or unbroken; in three out of four of the occasions on which it has been observed, it has been found to consist of *five* distinct elevations. The complete rise and fall has been termed the great symmetrical barometric wave of November, and as such has been considered

to result from the transit of a large wave; but there is great reason to believe that while it may be due to the transit of a normal wave of about fourteen days' amplitude, it also exhibits the transits of *five* secondary superposed waves of a similar character to those riding on the wave of seventeen days' interval, Oct. 1 to 19 (VII.). The great November wave consequently possesses a compound character: at its setting-in the barometer is generally *low*, sometimes below twenty-nine inches. This depression is succeeded by *two* well-marked undulations, varying from one to two days in duration. The central undulation, which also forms the apex of the great wave, is of larger extent, occupying from three to five days; when this has passed, two smaller undulations, corresponding to those at the commencement of the wave, make their appearance, and at the close of the last the wave terminates." This was the order of things in 1842, 1843 and 1845. The smaller undulations in these instances were not *identical*, that is, they did not occur on the same points of the wave in each case; but the two preceding and the two succeeding undulations to the larger or central one were well-marked; the physiognomy of the wave was readily recognized.

The wave of 1844 exhibited a striking departure from this type in two remarkable particulars; the epoch of transit and compound form of wave. The epoch was considerably earlier than in 1842, 1843 or 1845, namely Oct. 27; and the compound form consisted only of *three* instead of *five* undulations. The symmetry however was very apparent. This departure from the November type may probably be connected with the earlier occurrence of the wave; future observations will doubtless make us acquainted with its cause.

XII. Capt. Larcom of the Royal Engineers has most obligingly forwarded me, in addition to the observations made during the months of Oct., Nov. and Dec. 1845, curves of the barometric undulations observed at Dublin during the Novembers of 1829 to 1845 inclusive. These curves are so admirably calculated to confirm or disprove the views advanced in XI., that I avail myself of his permission to lay them before you; and I beg to acknowledge the great obligations I am under to that officer for the valuable assistance he has rendered me in this inquiry, both with respect to the immediate subject now under discussion (the great wave), and the return of the other extensive undulations before alluded to, which are admirably illustrated by the curves with which he has furnished me, and which I have much pleasure in submitting to the Association.

Review of the essential features of the Great Symmetrical Barometric Wave, as exhibited in a series of Curves representing the Barometric Undulations as observed at Dublin (Mount Joy, Ordnance Survey Office, Phœnix Park) during the Novembers of 1829 to 1845 inclusive.

[It may be well to notice, previous to proceeding with this review, that Dublin is not constantly situated in the line of greatest symmetry. In 1842 it appeared to form one of the points in the line, but the observations of Nov. 1845 have shown that this line is *not stable*. The line of greatest symmetry appeared on that occasion to coincide to a great extent with the southern coast of England, so that Dublin was thrown to the north of it. It is probable this line has a sort of oscillatory motion, and this may to a great extent explain the nodal character of Brussels as a barometric station, the fixed point in the line being not far removed from that city. The departure from symmetry on many of the returns of the great wave at Dublin, may readily be accounted for by the line of greatest symmetry being considerably removed from thence.]

1829. The great wave very distinct; the two anterior undulations well-marked, the two posterior not so distinct.

Transit of anterior trough, Nov. 9.
Transit of apex ..... „ 16.
Transit of posterior trough „ 23.
Amplitude in time, fourteen days.

1830. The symmetry of the great wave not so apparent; the subordinate undulations strongly marked.

Transit of anterior trough, Nov. 15.
Transit of apex ..... „ 23.

1831. The symmetry of the great wave clearly observable; its amplitude much smaller; *two* subordinate waves, one on the anterior, the other on the posterior slope, well-developed.

Transit of anterior trough, Nov. 6.
Transit of apex ..... „ 12.
Transit of posterior trough „ 15.
Amplitude in time, nine days.

1832. The symmetry very distinct on this occasion; the curve somewhat resembled that of 1842; the two anterior and two posterior undulations well-developed.

Transit of anterior trough, Nov. 9.
Transit of apex ..... „ 16.
Transit of posterior trough „ 23.
Amplitude in time, fourteen days.

The trough succeeding one of the posterior undulations is deeper than the posterior trough of the great wave, a circumstance that occurred in the year 1845 at this station (Dublin). The similarity between the transits of the great wave in 1829 and 1832, especially as to time, is highly interesting.

The remaining movements in this month were also strikingly symmetrical.

1833. The great wave very difficult to recognize; taking the well-marked depressions of the seventh and twenty-first as the anterior and posterior troughs, and regarding the movements between these epochs as due to the great wave, although greatly concealed by the strongly developed subordinate waves, we may regard the whole as a transit of the great wave at a station considerably removed from the line of greatest symmetry; the two anterior subordinate waves are strongly marked; the posterior appear to be broken into a number of smaller undulations.

Transit of anterior trough, Nov. 7.
Transit of apex ..... „ 13.
Transit of posterior trough „ 21.
Amplitude in time, fourteen days.

1834. The great wave very distinct, the subordinate waves but slightly developed.

Transit of anterior trough, Nov. 7.
Transit of apex ..... „ 14.
Transit of posterior trough „ 21.
Amplitude in time, fourteen days.

1835. The great wave very distinct and considerably amplified; the subordinate waves distinct but not strongly developed.

Transit of anterior trough, Nov. 3.
Transit of apex ..... „ 12.
Transit of posterior trough „ 21.
Amplitude in time, eighteen days.

1836. The great wave extremely difficult to recognize; two well-marked depressions on the 4th and 17th mark the terminations of a somewhat symmetrical system of movements. If these movements may be considered as

replacing the great wave, they are characterized by the most remarkable absence of the central undulation forming its crest; two of the subordinate undulations, equally posited with regard to the anterior and posterior troughs, are strongly and strikingly developed; and where the central undulation should have occurred, raising the apex above thirty inches, a great depression is seen.

1837. The great wave well-developed; the last posterior subordinate wave strongly developed.

Transit of anterior trough, Nov. 1 or Oct. 31.
Transit of apex ..... „ 6.
Transit of posterior trough „ 14.
Amplitude in time, fourteen days.

1838. The similarity between the curve of this year during the transit of the great wave and that of 1842 during the same period is very striking; the anterior slopes in each case are almost representatives of each other; the two subordinate waves on the anterior slopes are so nearly identical as to leave no doubt of the movements of 1842 being a most decided return of those of 1838; the similarity of the subordinate waves on the posterior slopes is not so distinct, the two are however well-marked. One striking difference between the curves must nevertheless be noticed; in 1838 the anterior trough was lowest, in 1842 the posterior was lowest.

Transit of anterior trough, Nov. 7.
Transit of apex ..... „ 12.
Transit of posterior trough „ 21.
Amplitude in time, fourteen days.

1839. The great wave in this year is very difficult to recognize. A maximum was passed on the 23rd, subordinate waves were developed on each side this maximum. There appears to be some similarity in the movements of this year to those of 1830, the subordinate waves are however not so distinct. Transit of apex, Nov. 23.

1840. In this year also the great wave is difficult to detect unless the broad maximum of the 26th forms its crest, in which case the posterior slope runs into December; this is borne out by the Greenwich observations, they however exhibit a large development of one of the subordinate waves on the posterior slope.

In the following table all the above features are collected. The amplitudes (in all cases except two being of the same extent, namely fourteen days) strongly confirm the views advanced. These views receive still greater confirmation from the epochs of the transits of the crests, which are arranged according to the *days* of the month on which they occurred in Table III.

TABLE II.

Year.	Anterior trough.	Crest.	Posterior trough.	Amplitude in time.	Remarks.
				Days.	
1829	Nov. 9	Nov. 16	Nov. 23	14	Very distinct.
1830	15	23	.....	.....	Symmetry not so apparent.
1831	6	12	15	9	Symmetry clearly observable.
1832	9	16	23	14	Symmetry very distinct.
1833	7	13	21	14	Wave very difficult to recognize.
1834	7	14	21	14	Very distinct,
1835	3	12	21	18	Very distinct.
1836	.....	.....	.....	.....	Extremely difficult to recognize.
1837	Oct. 31	6	14	14	Well-developed.
1838	Nov. 7	12	21	14	Similarity between 1838 & 1842 very great.
1839	.....	23	.....	.....	Wave very difficult to recognize.
1840	.....	.....	.....	.....	Difficult to detect.

TABLE III.

Distinct, well-marked transits.			Doubtful transits.		
Year.	Epoch of crest.	Value.	Year.	Epoch of crest.	Value.
1837	Nov. 6	30·20	1833	Nov. 13	30·03
1831	12	30·32	1830	23	30·12
1835	12	30·40	1839	23	30·18
1838	12	30·36	1840	26	30·28
1845	13	29·87			
1834	14	30·48			
1843	14	30·27			
1829	16	30·47			
1832	16	30·21			
1842	17	30·35			
1841	25	29·79			

From the above table it appears that with two exceptions in eleven years of distinct and well-marked transits of the great wave, the epochs of the maxima were confined to five days near the *middle* of the month, namely from the 12th to the 17th. The greater proportion, twelve years out of seventeen, including 1844, in which the wave has distinctly returned, greatly confirms the results noticed in sec. XI., namely that we have obtained the *type* of the barometric movements during fourteen days in November, more or less equally disposed about the middle of the month.

I cannot here avoid noticing another feature of a most interesting character which is very strikingly developed in these curves of November; it is apparently unconnected with the great wave. I allude to a general tendency to depression in the mercurial column about the last four or five days in the month: the following are the years in which this depression occurred:—

TABLE IV.

Year.	Epoch of minimum.	Value.
1829	Barometer falling.	
1830	Nov. 27	29·40
1832	28	29·19
1833	28	28·31
1834	28	28·97
1835	30	28·86
1836	27	28·81
1837	28	29·26
1838	28	27·77
1839	29	29·08
1841	29	28·47
1842	24*	28·38
1843	26	29·15
1844	28	29·74
1845	29	29·08

* A minimum occurred on Nov. 27, value 28·56.

This depression has occurred so regularly, only two exceptions having been observed in seventeen years, that it appears highly probable that its return may be expected with as much if not more regularity than that of the great wave itself, on or near the 28th of the month.

Section II.

Comparison of contemporaneous observations of the return of the Great Wave, Nov. 1845.

Of the observations that have come to hand, the following have been projected in curves in order to exhibit the characters of the great wave at various and distant stations; the epoch of the curves are Nov. 6 to 22, the duration of the great wave.

Scilly.	London.	Birmingham.
Helstone.	Yarmouth.	Stokesley.
St. Catherine's Point.	Haisboro.	Belfast.
Portsmouth.	Heligoland.	Galway.

These stations being considerably less than half the number from which observations have been received, it would be premature to draw any conclusions from a comparison of the curves, as well as appearing to give a preference to certain observations to the exclusion of others which have been executed with great care and fidelity, and from which in connection with the whole the most valuable results are likely to be arrived at. Every exertion would have been made to have completed the *rough* projection in curves of *all* the observations made during the transit of the great wave, in order to have submitted to the present meeting a first approximation to its general characters as exhibited at a diversity of stations, had not the publication of Mr. Brown's paper directed my attention to the arrangement of the aërial currents over the area of the British Isles during the transit of the great wave of Nov. 1842, the value of which I have alluded to in my introductory remarks.

It may however be important on this head to report the progress made, and to notice a few particulars merely as indicating the course pursued and the highly important results likely to be obtained from a complete discussion of the observations, not only for the period during the transit of the great wave, but also during the two months over which the observations extend. The curves are susceptible of a variety of arrangements, according as it may be deemed desirable to exhibit certain characteristic features of the normal or secondary waves. In submitting the projected curves to your notice on this occasion, I have selected that arrangement best calculated to exhibit,—first, the symmetrical character of the wave, and secondly, the direction in which this symmetrical character is most departed from.

The first two curves (Scilly and Helstone) are characterized by *three* periods of barometric readings of nearly the same value (slightly above twenty-nine inches), occurring on the 7th, 11th and 19th; between the 11th and 19th we find the central undulation forming the crest. The Helstone curve gives the greatest symmetrical arrangement. From these curves we may conclude that Scilly, and especially *Helstone*, were situated near the line of greatest symmetry. It is desirable particularly to notice, that at these stations the depressions of the 7th and 11th are about equal; *there appears to have been no fall from the commencement of the wave to the depression of the* 11th. Two distinct and well-marked waves (the two at the commencement of the great wave) are very discernible.

The next two curves, St. Catherine's Point (Isle of Wight) and Portsmouth, nearly agree with the two preceding, especially in the depressions of the 11th and 19th being of equal value. There is however a marked difference between these curves and those of Scilly and Helstone, in the two anterior waves being less developed, and the barometer exhibiting *a fall from the commencement of the great wave to the depression of the* 11th; and this fall is not only traced towards the E.N.E. through the stations London, Yarmouth and Har-

wich, Haisboro and Heligoland, but it increases in value as we approach the N.E. Now this state of things would result from a large wave passing from W.S.W., the posterior slope from Heligoland to Scilly. The readings for contemporaneous epochs at each E.N.E. station would be higher, and the fall greater. Taking the Helstone curve as the type of greatest symmetry—consisting in the *equality* of the three depressions above named, and the whole of the readings being above these depressions,—we have St. Catherine's Point and Portsmouth slightly departing from this symmetry, in the movements from the 7th to the 11th being thrown higher than those at Scilly and Helstone.

The curves in which we have traced the increase of the fall from the 7th to the 11th, exhibit a much greater departure from symmetry, in the depression of the 19th being lower than that of the 11th; and this difference increases in the order in which the curves are arranged, viz. London, Yarmouth, Haisboro, and Heligoland; and so great is this difference in the last three curves, that when combined with the fall from the 7th to the 11th, the barometric movements (abstracting the secondary waves) are of a downward character, that is, from the 7th to the 19th at these stations the tendency in the mercurial column is to fall very slowly and gently. At Scilly, Helstone, Portsmouth and the Isle of Wight, this tendency to fall did not exist.

Birmingham offers a striking difference from the last-named curves; the departure from symmetry is more apparent, but the downward movement is confined to the period between the depressions of the 11th and 19th. On this hand the Birmingham curve is connected with the south-eastern group, and clearly shows that the symmetry is greatly departed from to the N.E. of Scilly and Helstone. On the other hand, it is connected with the Scilly and Helstone curves by the movements of the 7th to the 11th, with a slighter development of the two anterior waves; if there is any difference, there is a slight rise from the 7th to the 11th.

Stokesley in Yorkshire presents features nearly approaching Birmingham, with a greater departure from symmetry, more especially in the depression of the 19th, which is deeper.

Belfast in Ireland exhibits the same departure from symmetry, in the depression of the 19th being thrown considerably below that of the 11th; but there is in this curve a certain return to a symmetrical arrangement of a somewhat different character to that exhibited by the curves of Scilly and Helstone; this consists in a most decided rise from the depression of the 7th to that of the 11th: the depressions of the 7th and 19th are thus brought nearer to an equality. In these respects (especially the latter) the curves of Belfast and Galway strikingly agree, and offer a decided contrast to the south-eastern group, which exhibits a fall to the depression of the 11th.

We thus have the area included by the angular points, Scilly, St. Catherine's Point, Heligoland, Belfast and Galway, parcelled out into three barometric areas. Near the extreme southern station the greatest symmetrical movements occurred; the south-western portion of our island may therefore be regarded as the area of greatest symmetry. A line passing from Scilly to Stokesley will divide the area into two portions, each characterized by different and opposite barometric movements, as far as the observations from the 7th to the 11th are concerned. On the N.W. of this line the barometer was rising, while on the S.E. of it, it was falling.

We noticed that the fall might be occasioned by a wave passing off toward the E.N.E.; now as a rise is occasioned by an anterior slope, a wave coming up from the N.W. would occasion the phænomena observed. In that portion of the area covered by the advancing wave the barometer would rise;

in that covered by the receding wave it would fall, while in that in which the two waves *interfered* so as to counteract each other, a quiescent state of the atmosphere would result. This appeared to be the case in the area of greatest symmetry, in which the larger waves so interfered as to exhibit the smaller secondary waves uninfluenced by them. This leads us to the real character of the symmetrical wave; not that there is such a reality in nature, as will be shown in the next part of this report, but that it results from the combination of large normal waves moving in different directions so as to interfere*.

I do not place any stress upon these deductions, as I have alluded to them merely to show the progress I have made, and that a complete discussion of the observations is likely to be attended with highly important results. The results of the examination of Mr. Brown's observations, as detailed in the next part of the report, are I apprehend calculated to throw much light on the inquiry, and when these observations are discussed with reference to the views there set forth, our knowledge of these interesting movements will I have no doubt be greatly increased.

Part II.

Examination of Mr. Brown's *paper on the Oscillations of the Barometer.*

In the Philosophical Magazine for April last, Mr. William Brown has published a paper on the oscillations of the barometer, with particular reference to the meteorological phænomena of *November* 1842. The object of this paper is to show that the barometric oscillations are produced by the *meeting* of opposite or nearly opposite aërial currents; that one current thus meeting or impinging on another, deflects it, and under some circumstances produces a rise of the mercurial column, but under others occasions a fall in many cases of considerable magnitude. In order to elucidate his views, Mr. Brown has collected barometric observations from eleven stations, which are scattered over an area included by the following angular points:—The Orkneys, Christiania in Norway, Paris, Plymouth and Cork. These observations are in most cases given as read off from the scale. In addition to these the paper is accompanied by six plates, in which the direction of the wind at numerous stations is indicated for every day during twenty-six days in the month by arrows. The anemonal observations published in the body of the paper not being in all cases for consecutive days, a comparison of them with the plates is rendered difficult; nevertheless the plates form a very valuable portion of the communication, and if they have been laid down from accurate observations, they furnish us with an important addition to our knowledge of the *arrangement* of the aërial currents, especially with respect to the distribution of pressure. It is a matter of regret that Mr. Brown did not so arrange his observations and plates, that the accuracy of the latter could have been seen by inspection.

I have alluded to this paper as peculiarly interesting at the present time, when the attention of meteorologists is directed to the important and interest-

* I have accompanied these curves with one on a smaller scale, representing observations at the Orkneys by the Rev. C. Clouston. The very striking departure from symmetry is extremely apparent in this curve by the depression of the 19th sinking considerably below the readings at any other station. This curve is more in accordance with those from the Irish stations in the rise from the 7th to the 11th, and it appears to be connected with Heligoland by the depression of the 11th being but slightly developed; in this respect it also agrees with the Stokesley curve. The depression of the 11th is very apparent in the S.W. curves, and it gradually decreases as we approach the N.E., where it is much less. The Orkneys appear to have been under the anterior slope of the wave coming from the N.W.

ing problem of the barometric oscillations,—one class of philosophers regarding them as only the effects of currents of air of unequal temperature and moisture; and another as the effects of undulations *progressing in the manner of waves of sound, and propagating themselves with great velocity over large portions of the earth's surface* (Report, 1845, page 30).

It is not my intention to enter into an examination of the conclusions and results which Mr. Brown has arrived at; as the question is open, I apprehend I shall not be doing an injustice to that gentleman by employing a rather different process to that which he has used, and further discussing the observations he has given. I beg to acknowledge the obligations I am under to him for these observations, and especially for the plates, of which I have before spoken: they are extremely interesting in the present inquiry.

In accordance with these remarks, I shall select the following stations from Mr. Brown's list:—the Orkneys, Belfast, Shields, Cork, Bristol, Plymouth, London, Paris, and Christiania. The reason I have omitted Glasgow and Armagh will be apparent from Mr. Brown's notes. As I intend to discuss these observations with especial reference to the wave hypothesis, I shall most cautiously avoid in my future remarks any thing that may at all bear on Mr. Brown's views. The plan I intend to proceed on is as follows. I shall select the middle observation of each day; at those stations where only two are given morning and evening; I shall take a mean of them. These observations I shall so arrange that they may exhibit the distribution of pressure over the area for each day—the line or lines of the greatest diminution of pressure—and the relation of such distribution and of such lines to the aërial currents or winds. As a convenient method of readily expressing these various relations and giving to the discussion that completeness which otherwise it would want, I shall adopt the wave hypothesis, and to every line of barometric maxima apply the term *crest* and to every line of minima the term *trough*. In a word, I shall regard the progress of the barometric and anemonal phænomena as the progress of *waves*. The observations will remain the same both in Mr. Brown's and my own discussions, the results only will be different; and it will remain for other philosophers, by more closely investigating the subject, and submitting the observations to a more rigorous and searching discussion, to advance this interesting inquiry and to become more intimately acquainted with the causes of these interesting phænomena.

Having announced my intention of discussing these observations on the wave hypothesis, it will be important before commencing such discussion to supply a deficiency in my two former reports, and endeavour to give a completeness to them which at present they are destitute of. The nature of the inquiry occasioned them to be drawn up and presented to the Association in a fragmentary manner, the first detailing the steps I intended to adopt in the examination of the great wave of Nov. 1842, and the second the further information I had obtained relative to this and other atmospheric undulatory movements; and to a certain extent the same remark will apply to the present report, embodying as it does the progress made since the last meeting of the Association. The deficiency to which I allude is the notion we form of an atmospheric wave; I shall therefore, previous to placing the discussion of Mr. Brown's observations before you, as clearly as I can, state the idea I entertain of such a wave, and in introducing it to your attention I shall avail myself of Mr. Scott Russell's designation of the elements of a wave as in figure 1, and then proceed with the definition of an atmospheric wave.

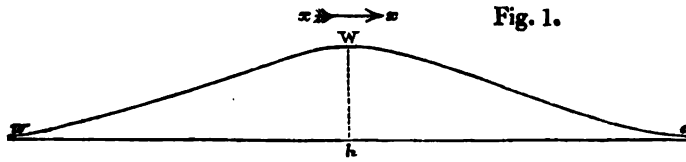
Section I.

Definition and Phænomena of an Atmospheric Wave.

When a number of barometric observations are projected on paper according to a suitable scale, and continued for months and years, the eye on contemplating them will recognize a variety of curved *forms*, some of large and some of small amplitude; some rising to a considerable altitude, others sinking far below the level, representing the mean barometric pressure at the station of observation. At first there appears but little regularity in these curvilinear records of the ever-shifting state of our atmosphere, but here and there the attentive observer will notice some similarity existing between two or more *individual* curves, and he may notice some which possess a certain symmetrical arrangement of the ascents and descents. In consequence of this similarity and symmetrical arrangement, he examines more carefully the records of barometric pressure, and not only discusses the observations at *one* station, but compares those observations with others made at *various* stations; and here again he finds apparent irregularity and confusion. The curves to a certain extent agree, but in many minor points they differ often very considerably, in some cases rising at one station while falling at another; this induces a still more minute and careful investigation: the distribution of pressure over the largest area he can command is carefully examined; and whether his stations are few or many at any given time, he finds on this area a point of maximum pressure and a point of minimum pressure; between these points he finds various pressures, generally increasing from the point of least pressure to the point of greatest pressure. On some occasions he finds a *line of high* pressure, stretching quite across the area, and on others a *line of low* pressure. By continuing his inquiries for successive epochs, he finds these lines of high and low pressure move across the area, or in other words, the high pressure or low pressure is gradually transferred from one point to another. He also finds at still more remote epochs other lines of high and low pressure, some having the same direction with the lines originally noticed, and others crossing the direction of the original lines at various angles.

The questions which now suggest themselves are the following. What are these movements? How can they be represented? In what manner can they be explained? A simple consideration of the curves suggests the idea of waves as explanatory of the phænomena, and the term atmospheric wave has been used to designate that *ideal individuality* which the mind attributes to the process which it observes of the successive change of place which the barometric maxima and minima undergo, and by which they regularly succeed each other over the area under examination; this ideal individuality has been employed as a mean of examining the movements just alluded to. The line of high pressure stretching across the area (the figure being supposed to cut this line transversely) has been termed the *crest*, W; the line of low pressure in advance of the crest, the *anterior trough*, *a* (the origin of Mr. Scott Russell's water wave); the line of low pressure succeeding

Fig. 1.



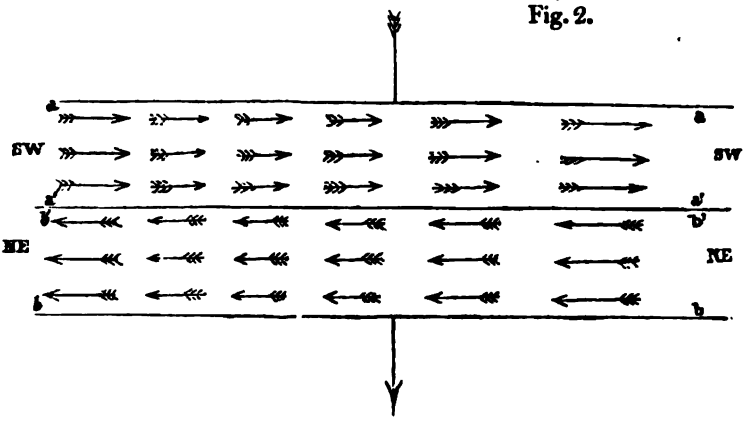
W, The crest. W a, The front. W w, The back.
w a, The amplitude. W h, The height.
a, The origin *. w, The end.

* Mr. Scott Russell designates the point *a* the *origin*; a better term I apprehend would be *commencement*.

the crest, the posterior trough, *w* (the end of Mr. Scott Russell's water wave); the line *w*...*h*, as measured by the mercurial column, the altitude of the wave; the slope W *a*, the anterior slope or front of the wave; the slope W *w*, the posterior slope or back of the wave; *w a* constitutes the amplitude of the wave, and *x* —— *x* in the same direction, the axis of translation.

The existence of atmospheric currents, especially the equatorial and polar, has been well-established; and there is a class of philosophers who attribute the barometric oscillations *entirely* to the effects of these currents as contra-distinguished to the effects of waves such as we have just mentioned. In contemplating the transference of the barometric maxima and minima, we regard only the *wave-motion*—but very different must be the *air-motion*. Prof. Dove, in his letter to Col. Sabine relative to the magnetical and meteorological observations, has announced his opinion that the equipoise of the atmosphere is maintained in the temperate zone by currents *on the same level flowing in opposite directions* (Report, 1845, page 61); thus we have a bed or stratum of air moving from the S.W., and on each side of this are strata of N.E. winds. We may here inquire, how are these alternate aërial currents related to the waves before alluded to? It is one of the objects of the following

Fig. 2.



discussion to exhibit this relation, which may be thus briefly expressed, at least in so far as the examination of the observations has yet extended*. Let the strata *a a a' a'*, *b' b' b b*, fig. 2, represent two parallel aërial currents, *a a a' a'* being from S.W. and *b' b' b b* from N.E., and conceive them both to advance from the N.W. in the direction of the large arrow, that is the strata themselves will advance with a *lateral* motion. Now conceive the barometer to commence rising just as the edge *b b* passes any line of country, and to continue rising until the edge *b' b'* arrives at that line, when the maximum is attained. The wind now changes and the barometer immediately begins to fall, and continues to fall until the edge *a a* coincides with the line of country on which *b b* first impinged. During this process we have all the phænomena exhibited by an atmospheric wave; when the edge *b b*, fig. 2, passes the line of country, the point *a*, fig. 1, of the wave (the anterior trough) transits that line of country and the barometer begins to rise with a N.E. wind. During the period the stratum *b' b' b b*, fig. 2, transits the line the anterior slope W *a*, fig. 1, passes; when the conterminous edges of the strata *a' a' b' b'*, fig. 2, pass, the crest W, fig. 1, extends in the direction of the preceding trough: the barometer now begins to fall, and when the edge *a a*, fig. 2, occupies the place of *b b*, also fig. 2, the descent of the mercurial column is completed; the

* For this knowledge I am indebted to Mr. Brown's plates.

posterior slope W *w*, fig. 1, has passed, and the posterior trough *w*, fig. 1, now occupies the line in which the anterior trough extended.

From these considerations, we readily see that the *wave* is a convenient method of representing the barometric fluctuations; we have already noticed the *wave motion*, the *lateral* transference of the parallel beds of aërial currents. We have seen that the rise is due to the anterior slope and the fall to the posterior; and we now further learn that the direction of the aërial current on the anterior slope is at right angles to the axis of translation directed towards the *left-hand*, while on the posterior slope it is the reverse; still at right angles to the axis of translation, but directed towards the *right-hand*.

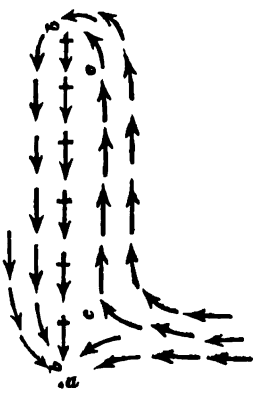
Having thus noticed the *wave-motion* with its accompanying *air-motion*, these interesting questions suggest themselves. How are the forces of this *air-motion* arranged? Do all the particles move with the same velocity? Are there different velocities in different parts of the wave? Our anemometers will answer these questions. In the troughs, the edges *b b a a*, the forces are strongest; as the barometer rises, the force gradually subsides; when the crest passes, it is zero; and as the barometer falls, it increases until the trough passes, when it is again strongest.

The examination of the transit of a single wave by means of barometric and anemonal observations, would be comparatively easy, but it seldom happens, from the operation of natural causes, that an isolated or solitary wave is produced. In almost every instance (except in those in which the generating power is very much greater than any which occasions the production of smaller waves) the wave is contemporaneous with others of equal, if not of greater magnitude, so that different systems are in motion at the same time, each individual pursuing its own course, and although perfectly independent of every other, yet greatly modifying the *resulting phænomena* as exhibited by the barometer and anemometer. When therefore we proceed with the examination of certain barometric and anemonal phænomena in the manner above alluded to, we are speedily perplexed with the barometric and anemonal effects of *cross waves*; the flowing of one set of waves in a certain direction is apparently interrupted and interfered with by another in a different direction, and before the first set can be exhibited with its proper proportions, and the true altitudes, amplitudes, velocities, and directions of its individual waves assigned, all the phænomena of the other set must be carefully disentangled and separated from the aggregate phænomena presented by the contemporaneous systems. The barometric curve, including a complete rise and fall at any one station, is *not* the curve resulting from the transit of any *one* wave; it does *not* represent the *form* of any *reality* in nature; but it *does* represent, and is an exponent of the effects resulting from the contemporaneous transits of waves, or systems of waves, such as have been described.

The contemporaneous existence of these *cross waves*, with their appropriate aërial currents, as manifested by the barometer and anemometer, appears likely to form an *experimentum crucis* between the conflicting hypotheses, the oscillations of the barometer as dependent on waves, in contradistinction to that of the same oscillations as dependent only on the aërial currents. When a current meets with another at any angle, both are altered in direction; and if the forces are different, the united current proceeds with an increased or diminished strength, according to the situation of the station relative to the separate currents before confluence. This union would of course influence the barometer; if the station is in a current of slow progress, and the air possesses considerable density, the barometer would *fall* upon the new current being established; while at another station, where the force of the wind is great and the pressure low, it would rise when the con-

fluence took place. These phænomena, however, could only occur upon the impinging of currents; upon M. Dove's theory of parallel currents in opposite directions, it does not appear likely that they can exist. Mr. Dove has suggested that these parallel currents may be shifting ones, and we have supposed that the parallel currents of N.E. and S.W. winds may advance from the N.W. with a lateral motion. The same cause that produces the opposite and superposed equatorial and polar currents, will also give rise to the same opposite *but* parallel currents in the temperate zone, namely, the ascending column of heated and consequently rarefied air. Now it is well known that in stormy weather, when the wind is blowing with great force, the barometer being nearly at its minimum, upon the *wind changing* the barometer *commences rising*; the wind however continues to blow with about the same force as it did with the previous falling barometer. Upon M. Dove's view of parallel and opposite currents, somewhere in or near the line forming the boundary between the currents, towards or in the torrid zone, we ought to find the point of rarefaction, and to this point the N.E. current would rush with the greatest force to supply the ascending column of heated air*. This N.E. current would be compensated by a S.W. current of nearly or quite the same force, situated just to the S.E. of it, as in fig. 3, in which let a point of rarefaction, *a* for instance, exist in any locality, so that a N.E. current may be established to supply the ascending column; suppose the greatest force to exist along the line of crossed arrows *b b*, the air would be drawn from the end of this line to fill up the vacuum at *a*, and a compensating S.W. current, *c c*, established. This S.W. current would be established partly by the descent of the overflowing current at *a*, and partly by the rush to supply the air constantly drawn off to feed the ascending column. When however it is once established, the velocity of the line of S.W. current nearest to the N.E. would probably be equal, or nearly so, to that of the N.E. current itself.

Fig. 3.



In this way it is easy to conceive that a complete barometric wave may be produced; the lines of greatest velocity of the parallel currents will indicate the trough; the rapidity with which the currents pass in opposite directions greatly diminishes the pressure, and according to this view somewhere near the direction of the trough and to the S.W. of it, we ought to find the point of greatest rarefaction: the velocity decreases on each side this trough, and with this decrease of velocity the pressure increases, so that we have a

* In attributing the greatest force to the N.E. current, I do not by any means wish to put forward or support any hypothesis that would at all interfere with the well-known fact, that the greatest force is usually manifested by S.W. winds. The point to which I wish more particularly to solicit the attention of the Association is this, *the cause which induces the south-westerly current itself.* This must reside in or near the torrid zone. Here we have a sufficient cause; we are presented with phænomena fully adequate to explain an influx of *cool* air from the N.E. This is the current that must first be established, and in the first instance its force will be *greatest.* We have however only to turn to Prof. Dove's letter to Col. Sabine (Report, 1845, p. 61), and we shall at once find the reason why S.W. winds manifest by means of our instruments the greatest force. The N.E. currents are *narrower*, and the force *soon abates* as they pass over towards the S.E.; while on the other hand the same station is not only *oftener*, but *longer* in the S.W. currents, and as the line of greatest force approaches, the force increases, on some occasions very rapidly, until the wind changes. The line of greatest force soon passes the station, so that upon a mean of numerous observations the south-westerly wind exhibits the *greatest* force.

distribution of pressure of a *wave form* gradually rising on each side the trough, the *pressure* being dependent on the velocity of the parallel currents.

The constant ascent of air at the point of rarefaction would continually draw off a quantity of air from the S.E. side of the line of greatest velocity *b*—*b*, fig. 3, and this would be attended with two results; first, there would be a *real* hollow or trough formed in the line of junction of the parallel currents; and secondly, this line would gradually advance towards the S.E.; for as more air would be drawn off from that side, the whole body of air would advance in that direction to supply the deficiency; and should the rarefying process cease, we can readily conceive that not only will the *wave-form* be continued, but also *wave-motion*. The establishment of the parallel currents will give the *air-motion*; the diminution of pressure towards the lines of greatest velocity will give the *wave-form*; and the drawing-off of air from the S.E. will induce the *wave-motion*. The wave thus generated is *negative*; it consists of a hollow produced by the ascending current of heated air carrying off a considerable portion of air set in motion by this ascending column, and its direction of motion is determined by more air being drawn off from the S.E. slope than the N.W.

It might be expected that as the trough passed, a motion of the air or wind from the N.W. (the body of air moving from that quarter to supply the constant drain in feeding the ascending current) would be observed; but so strong must the parallel currents be which give rise to the wave, that such motion would doubtless be concealed by them.

The barometric and anemonal phænomena would present very regular phases, provided there was only one system of *waves*, one set of parallel and opposite *currents* constantly passing from N.W. to S.E. I have however in former reports shown that different systems have contemporaneously traversed the area over which the observations have extended, and the discussion of Mr. Brown's observations has clearly brought to light a set of parallel and opposite currents at right angles to those we have just been contemplating, namely, from N.W. and S.E. with a *wave-motion* towards the N.E., producing the cross waves which occasion the complexity before alluded to. The late Professor Daniell has remarked that the curves increase in range towards the N.W., and in general the neighbourhood of *water* presents curves remarkable for the boldness of their contour and the large extent of their range. In venturing a speculation on these cross waves from the S.W. with parallel and opposite currents from N.W. and S.E., I should be inclined to attribute them to the effect of the solar influence on the terrestrial surface, extending from Cape Verd in Africa to the extreme north of Lapland in Europe. This surface extends from S.W. to N.E., or somewhat in that direction. It may be remarked, that to the *north-east* of Cape Verd is situated the Sahara or Great Desert of Africa, and here we have a great rarefying surface. To the north-west or west-north-west of this extensive rarefying surface, the broadest part of the Atlantic ocean is situated. The relative positions of the Great Desert and the broadest extent of the Atlantic will produce a great indraught of cool air from the ocean; the direction of this wind will be W.N.W. or N.W. To the north-east of this current, probably in the neighbourhood of Morocco, Fez, Algiers, Spain and Portugal, and the north-west portions of the Mediterranean sea, we ought to find the counter current from the S.E. or E.S.E., the two portions in juxtaposition moving with the greatest velocity. Somewhere in the Atlantic the turning-point of these oppositely directed currents should exist. The line of junction of these parallel currents will determine the trough of the wave, and as before shown, in consequence of the air being drawn off from the north-east to supply the ascending current, the wave will progress towards that quarter;

the barometer first descending with the S.E. wind as the trough approaches stations to the N.E., and rising with the N.W. as the current produced by the rarefaction approaches, until the crest passes, when the new counter current or slope of the next wave would set in *.

Pursuing this idea further, there can be no question that Ireland and Scotland become points, or unitedly constitute a great point of rarefaction, forming as they do the nearest land to the northern part of the Atlantic, the land becoming hotter than the neighbouring water, and in consequence a N.W. current with its compensating current from the S.E. is induced. Not only will the rapidity of the currents reduce the pressure, but the ascending column from the land will transfer some of the air into the general current of the atmosphere, and there will be a real difference in the distribution of air as well as pressure; a section transverse to the line of greatest velocity will exhibit a hollow or trough, and the same phænomena will result from this arrangement of the aërial currents as we noticed arising from the N.E. and S.W. currents, the only difference being in direction.

The following marine stations are admirably suited for testing the views just advanced, and tracing a wave of this system from the most western point of Africa to the north of Europe.

Cape Verd.	Lisbon.	Glasgow.
Cape Verd Islands.	Oporto.	Inverness.
The Canaries and Madeiras.	Corunna.	The Western Isles.
The Azores as an outlying station.	Brest.	The Orkneys.
	The Scilly Islands.	The Shetland Isles.
A station in Morocco near Cape Cantin.	Cape Clear.	Christiania.
	Limerick.	Coast of Norway near the Arctic Circle.
Tangier.	Galway.	
Gibraltar.	Markree.	Hammerfest or Alten.
Cadiz.		

A station in Iceland as an outlier would be very valuable.

The following inland stations are calculated to exhibit the influence of the land in modifying the waves in their progress towards the N.E.

St. Petersburg.	Prague.	Venice.	Naples.
Warsaw.	Vienna.	Rome.	Tunis.

In thus considering these rectangularly posited systems of parallel and opposite currents, many complex anemonal and barometric phænomena receive an easy explanation, particularly the revolution of the vane in one uniform direction, and the barometric wind-rose. When the conterminous edges of any two currents pass a station, the barometer is either at a maximum or minimum with respect to that particular system of currents; the wind also changes at this time. If the barometer has previously been rising with a north-easterly wind, it now begins to fall with a south-westerly: the cross currents are however passing at this time with a lateral motion towards the N.E.; in this set of cross currents the barometer will rise with a north-westerly wind and fall with a south-easterly. Suppose while the posterior slope of a N.W. wave transits, wind S.W., and before its trough passes, the trough of the cross wave from the S.W. also transits, and is immediately succeeded by the following anterior slope with its N.W. current, the wind will pass from S.W. to W. Now while this slope continues, upon the trough of the N.W. system passing, the wind changes to N.E., and the resultant of the two currents is N. It is easy to pursue this reasoning, and thus trace the changes of the wind arising from these two cross systems completely round the compass.

* In the above suggestion I have considered the northern portion of the African continent as inducing the N.W. current, but of course, the entire surface, as far as the extreme north of Europe, including Great Britain and Ireland, will act as a rarefying surface.

The two systems of cross currents naturally divide themselves into four beds of opposite currents, namely, N.E. S.W., N.W. S.E.; with the first of each system, N.E. N.W., the barometer rises, and with the last of each, S.W. S.E., it falls, so that in the barometric wind-rose the maximum is found about the N.E., the prevailing system, and the minimum near the S.W., the opposite current of this system.

The extent of arc which the wind-vane frequently describes, especially in stormy weather, also receives an explanation from these systems of cross currents. A contemporaneous S.W. with a N.W. wind will occasion large arcs to be described between these points; the south-westerly gusts prevailing, directing the vane to that quarter; and the north-westerly immediately following, instantly occasions a change carrying the vane towards the N.W. These sudden and extensive changes are rendered more distinctly perceptible by means of a small kite flown with about 250 or 300 feet of string, or even more; the distinctness and independence of the direction of the two currents are readily seen, as well as the difference in their strength.

Col. Sabine has shown in his Report on the Meteorology of Toronto, that the intensity of the wind increases as the temperature increases. The consideration of these cross currents opens up to us another mode of contemplating the force of the wind. It appears probable that the force diminishes on each side the line of greatest velocity. Now in order to obtain the true expression of this force, its numerical value, it will be important to correct the results, either anemometric or those obtained by estimation for the daily period; this will give the value of the force of the currents then passing, and will in a great measure test the hypothesis.

Section II.

Discussion of Mr. Brown's *Observations.*

In the following discussion I have first arranged such of the observations collected by Mr. Brown, or deductions from them, as indicate the barometric pressure about the middle of each day at the stations before-named, as near as the data furnished by that gentleman will allow. These observations or deductions will be found in Table V. The arrangement is such that the eye may readily ascertain the barometric state of the atmosphere at any station on any day embraced by the area and period included in the table. The changes at any one station are also readily seen, the altitudes above 30 inches being distinguished from those between 29 and 30, and those below 29 also being distinguished from the rest. This table forms the basis of the following deductions which have been thus arrived at. The values corresponding to each day have been arranged with especial reference to the maximum and minimum of that day *in space*, that is, the station exhibiting the greatest pressure on any particular day has generally been placed first on the list for that day; and that exhibiting the least, last. At the head of each list are placed the directions of the crests as indicated by the observations. Crests passing from N.W. to S.E. are distinguished by the odd numbers, and those passing from S.W. to N.E. by the even. When the observations give two slopes from a crest or trough passing between such slopes, the observations have been arranged to exhibit this. After the arrangement of the observations, the lines of the greatest diminution of pressure corresponding in a majority of cases to tranverse sections of the waves, and exhibiting either their anterior or posterior slopes, are inserted. These are succeeded by the direction of the wind on each side of the crests as given in Mr. Brown's plates, and the discussion of each day's observation is concluded by a few explanatory notes.

TABLE V.—Barometric Observations, November 1842.

Station.	In.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
Orkneys . .	30	·16	·23	·24	·49	·52	·46	·15	·63	·80	·39	·24	·10	·35
Belfast . . .	30	·23	·18	·18	·45	·55	·51	·43	·04	·41	·57	·02	·21	·27
Shields . . .	30	·17	·19	·10	·34	·33	·35	·27	·97	·28	·58	·99	·07	·24
Cork. . . .	30	·15	·02	·83	·16	·32	·30	·38	·01	·42	·20	·91	·31	·40
Bristol . . .	30	·18	·05	·96	·14	·20		·18	·07	·60	·46	·03	·31	
Plymouth . .	30	·21	·04	·91	·15	·22	·24	·24	·13	·72	·48	·12	·46	·46
London. . .	30	·17	·10	·96	·13	·12	·16	·13	·08	·70	·64	·00	·33	·26
Paris . . .	30	·04	·86	·73	·80	·75	·83	·89	·90	·76	·63	·25	·43	·53
Christiania. .	29	·78	·11	·31	·37	·27	·21	·02	·67	·37	·24	·48	·20	·94

Station.	In.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.
Orkneys . .	29	·76	·01	·22	·35	·18	·91	·96	·86	·43	·33	·10	·07	·10
Belfast . . .	29	·91	·82	·06	·51	·37	·86	·91	·95	·42	·32	·79	·82	·04
Shields . . .	29	·82	·83	·08	·45	·42	·77	·85	·89	·30	·27	·78	·82	·99
Cork. . . .	29	·60	·37	·70	·31	·18	·92	·80	·83	·58	·10	·54	·80	·04
Bristol . . .	29	·65	·61	·78	·36	·42	·98		·79	·39	·26	·79	·84	·14
Plymouth . .	29	·68	·64	·70	·36	·47	·14	·73	·79	·53	·30	·91	·93	·20
London. . .	29	·80	·62	·79	·36	·53	·06	·77	·82	·28	·59	·92	·88	·17
Paris . . .	29	·67	·55	·50	·99	·38	·17	·55	·57	·13	·41	·02	·01	·17
Christiania. .	29	·25	·70	·86	·94	·11	·91	·60	·54	·55	·62	·66	·62	·57

The numbers in the columns immediately succeeding the names of the stations indicate the initial inch of the barometric readings of the 1st and 14th of November, the succeeding numbers are decimals of an inch. Observations above 30 inches are not underlined. Those between 29 and 30 inches have a single line —, and those below 29 inches a double line =.

November 1, 1842.

Crest No. 1.

N.W.——————S.E.

Crest No. 2.

S.W.——————N.E.

Anterior slope, Crest No. 1.

Max. Belfast .... 30·33
Shields .... 30·17
Orkneys .... 30·16
Christiania .. 29·78

Posterior slope, Crest No. 1.

Max. Belfast .... 30·33
Bristol .... 30·18
Plymouth .. 30·21
Cork ..... 30·15

Anterior slope, Crest No. 2.

London ..... 30·17
Paris ..... 30·04

Slopes.—Lines of greatest diminution of pressure.

Anterior slope, Crest No. 1, Belfast to Christiania.... ·55
„ „ „ 2, „ Paris ..... ·29

Currents.—Wind on N.E. side of Crest No. 1, N.W.
„ S.W. „ „ „ changing to S.E.

A decided crest or line of maximum pressure passes across Ireland and England with a general direction N.W.—S.E. The stations in the first column are N.E. of this crest, the pressure gradually decreasing. The line of greatest diminution is Belfast to Christiania. This indicates the anterior slope of the wave; altitude from Christiania ·55. The wind along the slope is N.W. The stations in the second column are S.W. of the crest; at these stations the pressure but slightly differs from the maximum; the wind appears to be changing to S.E. in the S.W. part of our island; this wind is that due to the posterior slope. The diminution of pressure from Belfast to Paris = ·29. This indicates the anterior slope of a wave at or nearly at right angles to the former. At two stations the wind is N.E., that of the anterior slope of this system.

November 2, 1842.

Crest No. 1.

N.W.——————S.E.

Crest No. 2.

S.W.——————N.E.

Anterior slope, Crest No. 1.			Anterior slope, Crest No. 2.		
Max.	Orkneys	30·23	Max.	Orkneys ..	30·23
	Christiania ..	30·11		Shields	30·19
				Belfast	30·18
				London ..	30·10
				Bristol	30·05
				Plymouth ..	30·04
				Cork.....	29·92
				Paris.....	29·86

Slopes.—Lines of greatest diminution of pressure.

Anterior slope, Crest No. 2, Orkneys to Paris..... ·37
Posterior slope, Crest No. 1, „ Cork..... ·31

Currents.—Wind on S.W. side of Crest No. 1, mostly S.E.
„ S.E. „ „ 2, a few N.E.

The progression of the crest, which was so distinctly developed on the 1st towards the N.E. and the succeeding S.E. current, is most decided. The altitudes at Belfast and Christiania are nearly equal, indicating that the crest is between them. The wind, with but few exceptions, is S.E. over nearly the whole of Great Britain and Ireland, while at Christiania on the anterior slope it is N.N.W. The posterior slope from the Orkneys to Cork is well-exhibited. Altitude from Cork to Orkneys = ·31.

The line of greatest diminution of pressure this day, Orkneys to Paris, crosses that of yesterday nearly at right angles; this arises from the advance of the anterior slope of the wave (Crest No. 2); at a few stations the wind is N.E. that of the advancing slope, and these in the neighbourhood of a line where the wind appears to have been variable. Altitude from Paris to Orkneys = ·37.

November 3, 1842.

Crest No. 1.

N.W.——————S.E.

Crest No. 2.

S.W.——————N.E.

Posterior slope, Crest No. 1.

Max.	Christiania..	30·31	Bristol	29·96
	Orkneys....	30·24	Plymouth ..	29·91
	Belfast	30·18	Cork	29·83
	Shields	30·10	Paris	29·73
	London	29·96		

Slope.—Line of greatest diminution of pressure.

Posterior slope, Crest No. 1, Christiania to Paris..... ·58

Currents.—Wind on S.W. side of Crest No. 1, S.E.

„ S.E. „ „ 2, N.E. towards trough.

„ N.E. „ „ 1, N.W. Christiania.

The crest No. 1 is now approaching Christiania. The observations of this day offer a decided contrast to those of the 1st; the posterior slope of crest No. 1 is well-developed, the point of greatest pressure being to the *west* of Christiania: the point of least pressure is still Paris, where the barometer has been falling since the 1st: this station appears to be near the intersection of the troughs of both waves. The progress of the maximum point is extremely interesting. On the 1st we find it at Belfast, on the 2nd at the Orkneys, and on the 3rd at Christiania; the direction of the progression is consequently undoubted. The general direction of the wind over England, Scotland and Ireland, is S.E.; that due to the posterior slope, at Paris and in the South-east of England, the wind is E. and N.E., the anterior slope of crest No. 2.

November 4, 1842.

Crest No. 1.

N.W.——————S.E.

Crest No. 2.

S.W.——————N.E.

Anterior slope, Crest No. 2.

Max.	Orkneys....	30·49	Plymouth ..	30·15
	Belfast	30·45	Bristol	30·14
	Christiania..	30·37	London	30·13
	Shields	30·34	Paris	29·80
	Cork	30·16		

Slope.—Line of greatest diminution of pressure.

Anterior slope, Crest No. 2, Orkneys to Paris..... ·69

Currents.—Wind on S.W. side of Crest No. 1, S.E. at a few stations.

„ S.E. „ „ 2, N.E.

The anterior slope of crest No. 2 is well-developed, and the evidence of its extending over the whole of the British islands extremely strong; also the establishment of its proper wind N.E.; a few stations exhibit the S.E. wind as the posterior slope of crest No. 1 is passing off. The line of the greatest diminution of pressure is identical with that of the 2nd, namely, Orkneys to Paris, but it is nearly doubled in value, being now equal to ·69, showing that the greatest curvature is approaching.

The crest No. 1 appears now to be over Christiania, or a little to the east of it.

November 5, 1842.

Crest No. 1.

N.W.——————————S.E.

Crest No. 2.

S.W.——————————N.E.

Max.	Belfast	30·55	Probable direction of Crest No. 2.
	Orkneys.....	30·52	
	Cork	30·32	
	Shields	30·33	Anterior slope of Crest No. 2.
	Christiania....	30·27	
	Plymouth	30·22	
	Bristol	30·20	
	London	30·12	
	Paris	29·75	

Slope.—Line of greatest diminution of pressure.

Anterior slope, Crest No. 2, Belfast to Paris.... ·80.

Currents.—Wind on S.E. side of Crest No. 2, N.E.

The anterior slope of crest No. 2, extending from Cork, Belfast and the Orkneys to Paris, is well-developed. Belfast is the highest point, Paris the lowest. Altitude from Paris ·80. The posterior slope of crest No. 1 is now scarcely perceptible. The wind is that due to the anterior slope of crest No. 2. The following table will show the gradual approach of the anterior slope of this wave. Paris the lowest point:—

	Belfast to Paris.
November 1	·29
„ 2	·32
„ 3	·45
„ 4	·65
„ 5	·80

November 6, 1842.

Crest No. 2.

S.W.——————————N.E.

Anterior slope, Crest No. 2.

Max.	Belfast	30·51	Plymouth ..	30·24
	Orkneys....	30·46	Christiania..	30·21
	Shields	30·35	London	30·16
	Cork	30·30	Paris	29·83

Slope.—Line of greatest diminution of pressure.

Anterior slope, Crest No. 2, Belfast to Paris.... ·68.

Currents.—Wind, with but few exceptions, N.E., anterior slope of Crest No. 2.

Nearly the same state of the barometer is maintained over the area as on the 5th, with nearly similar winds. The anterior slope of crest No. 2 is still strikingly developed. The greatest curvature has passed with a very slight *fall* at Belfast and a very slight *rise* at Paris.

November 7, 1842.

Crest No. 2.

S.W.——————————N.E.

Crest No. 3.

N.W.——————————S.E.

Crest No. 2.			Posterior slope, Crest No. 2.		
Max.	Belfast....	30·43	Max.	Belfast....	30·43
	Cork	30·33		Orkneys ..	30·15
	Shields ..	30·27			
	Plymouth	30·24			
	Bristol....	30·18			
	London ..	30·13	Anterior slope, Crest No. 2.		
	Christiania	30·02			
	Paris	29·89			

Slope.—Line of greatest diminution of pressure.

Anterior slope, Crest No. 2, Belfast to Paris..... ·54.

Currents.—Wind on S.E. side of Crest No. 2, N.E.

„ N.W. „ „ S.W.

„ N.E. „ 3, N.W. { advancing anterior slope of new wave.

The crest No. 2 has now passed the Orkneys, which exhibits a falling barometer and the S.W. wind. The trough between crests 1 and 3 is now to the N.E. of Belfast and Paris; the higher readings in the south-west part of the area, with the lower in the north-east, clearly indicate the advancing anterior slope of the new wave. Diminution of pressure from Belfast to Christiania, ·41.

November 8, 1842.

Crest No. 2.

S.W.——————————N.E.

Crest No. 3.

N.W.——————————S.E.

Anterior slope, Crest No. 2.			Posterior slope, Crest No. 2.		
Max.	Plymouth..	30·13	Max.	Plymouth..	30·13
	London ..	30·08		Cork.....	30·01
	Bristol....	30·07			
	Paris	29·90			

Anterior slope of Crest No. 3.

London.....	30·08	Christiania.....	29·67
Belfast	30·04	Orkneys.....	29·63
Shields	29·97		

Line of greatest diminution of pressure. Plymouth to Orkneys .. ·50

Currents.—Wind on S.E. side of Crest No. 2, N.E.

„ N.W. „ 2, S.W.

„ N.E. „ 3, N.W.

The crest No. 2 appears on this day to pass from Plymouth towards Bristol and London. The direction of the line of greatest diminution of pressure varies considerably from that of the three preceding days; this partly arises from the great fall which commenced on this day at the northern stations, Orkneys, Belfast and Christiania; and from the anterior slope of the wave (crest No. 3). The direction of the wind is closely in accordance with crest No. 2, passing in the direction from Plymouth towards London, being S.W. on the north-west side of the crest.

Anterior slope, Crest No. 2.

The wave (crest No. 2), with its front towards the south-east, has been very distinctly developed during the preceding days. The altitude of the crest appears to have *subsided* as the wave progressed; the highest reading at Belfast was 30·55 on the 5th, at London 30·16 on the 6th, and at Paris 29·90 on the 8th. The following tables exhibit the features of the anterior slope. Table VI. shows the barometric rise and fall at stations arranged more or less with regard to a line cutting the crest of the wave transversely. The depressing influence of the wave, crest No. 1, is clearly seen at London and Paris on the 5th. Tables VII., VIII. and IX. exhibit the depression of the south-easterly stations below those to the north-west of them while the anterior slope passed.

TABLE VI.—Barometric differences arising from Anterior and Posterior Slopes of Crest No. 2.

Epoch.	Belfast.	Bristol.	London.	Paris.
Nov. 2	−·15	−·13	−·07	−·18
„ 3	·00	−·09	−·14	−·13
„ 4	+·27	+·18	+·17	+·07
„ 5	+·10	+·06	−·01	−·05
„ 6	−·04	.....	+·04	+·08
„ 7	−·08	−·01?	−·03	+·06
„ 8	−·39	−·11	−·05	+·01

TABLE VII.—Barometric differences arising from Anterior Slope of Crest No. 2.

Epoch.	Belfast.	London.	London. ±
Nov. 1	30·33	30·17	−·16
„ 2	·18	·10	−·08
„ 3	·18	29·96	−·22
„ 4	·45	30·13	−·32
„ 5	·55	·12	−·43
„ 6	·51	·16	−·35
„ 7	·43	·13	−·30
„ 8	30·04	30·08	+·04

TABLE VIII.

Epoch.	London.	Paris.	Paris. ±
Nov. 1	30·17	30·04	−·13
„ 2	·10	29·86	−·24
„ 3	29·96	·73	−·23
„ 4	30·13	·80	−·33
„ 5	·12	·75	−·37
„ 6	·16	·83	−·33
„ 7	·13	·89	−·24
„ 8	30·08	29·90	−·18

TABLE IX.

Epoch.	Belfast.	Paris.	Paris. ±
Nov. 1	30·33	30·04	−·29
„ 2	·18	29·86	−·32
„ 3	·18	·73	−·45
„ 4	·45	·80	−·65
„ 5	·55	·75	−·80
„ 6	·51	·83	−·68
„ 7	·43	·89	−·54
„ 8	30·04	29·90	−·14

November 9, 1842.

Crest No. 2.

S.W.——————— N.E.

Posterior slope, Crest No. 2.

Max.	Paris	29·76	Belfast	29·41
	Plymouth ..	29·72	Christiania..	29·37
	London	29·70	Shields	29·28
	Bristol	29·60	Orkneys....	28·80
	Cork	29·42		

Slope.—Line of the greatest diminution of pressure. Paris to Orkneys, ·96
Current.—Wind on N.W. side of crest, S.W., fully established.

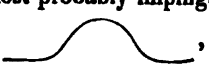
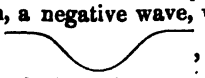
The posterior slope of crest No. 2 now comes into full view, stretching from Paris to the north-west coasts of Ireland and Scotland, with its proper wind S.W. The altitude of this slope from the Orkneys to Paris is ·96. The greatest altitude of the anterior slope, from Paris to Belfast, was ·80. It will be seen that the greatest oscillation has been in the north-west, Paris exhibiting but a very slight oscillation, ·17, while that at the Orkneys has amounted to 1·72.

The following table exhibits the fall of the barometer on the 8th and 9th:

TABLE X.—Fall of Barometer, November 8 and 9, 1842.

Station.	November 8.	November 9.
Orkneys.....	·52	·83
Christiania.....	·35	·30
Belfast.....	·39	·63
Shields.....	·30	·69
Cork.....	·32	·59
Bristol.....	·11	·47
Plymouth.....	·11	·41
London.....	·05	·38
Paris.....	+·01	·14

From these numbers we learn that the greatest barometric fall, as well as the greatest oscillation, occurred in the N.W. The fall gradually decreases as we approach the S.E.

It appears to me that the difference of oscillation at two stations, as the Orkneys and Paris, may be thus explained. The curves in the north-west of Ireland, as determined by the discussion of Sir John Herschel's hourly-observations, are remarkable for boldness and freedom of contour and great range of fluctuation. The late Professor Daniell found, from an examination of the Manheim observations, that the range increased towards the north-west, and that the greatest oscillation occurred in the neighbourhood of water. Now a wave generated in any way and approaching the continent of Europe from the north-west, would most probably impinge on it with a high and in some cases acuminated crest  , but as it passed onward the crest would gradually subside , so that at stations considerably to the south-east the fluctuations would be very much less than at or near its point of genesis. Again, a negative wave, with a deep trough also approaching from the north-west  , would present large fluctuations as it impinged on the land; but after passing on-

wards, the opposite to subsidence would take place; the depth of trough would decrease ⌒, and the oscillations to the south-east would also decrease. Such phænomena appear to be presented by the observations from the 5th to the 10th of November 1842.

November 10, 1842.

Crest No. 2.

S.W.——————N.E.

Crest No. 3.

N.W.——————S.E.

Max.	London.....	29·64	Near crest No. 3.
	Paris.....	29·63	
	Shields.....	29·58	
	Belfast.....	29·57	
	Plymouth....	29·48	Under posterior slope, No. 3.
	Bristol	29·46	
	Cork.....	29·20	
	Orkneys	29·39	Under anterior slope, No. 3.
	Christiania ..	29·24	

Slope.—Line of greatest diminution of pressure on posterior slope of Crest No. 2. London to Cork ..... ·44.

Altitude of anterior slope, Crest No. 3. Christiania to London .. ·40.

Altitude of posterior slope, Crest No. 3. Cork to Belfast..... ·37.

Currents.—Wind on N.E. side of Crest No. 3, N.W.

„ S.W. „ „ 3, S.E.

„ posterior slope of Crest No. 2, S.W.

„ anterior slope of Crest No. 4, N.E.

Trough succeeding Crest No. 2 now transits Christiania.

The direction of the crest No. 3 is nearly identical with that of No. 1, which passed Great Britain and Ireland on the 1st. This appears to suggest that they were either successive crests of the same system of waves, or were succeeding waves produced by the same disturbing causes. The altitude of crest No. 3 is about half an inch less than that of crest No. 1; but between the transits of the two crests a wave from the N.W. with a deep posterior trough has passed the area, which has probably depressed crest No. 3. The interval between the crests Nos. 1 and 3 is equal to nine days.

It was noticed in the remarks on the 9th, that the great difference in the oscillation at the Orkneys and Paris most probably resulted from the subsidence of the crest as it progressed. The crest No. 3 came from the S.W., so that a line from Plymouth to Christiania would cut it more or less transversely; the ranges however are nearly the same at both stations. The crest which traversed England on the 1st arrived at Christiania on the 4th; at this time the barometer had commenced rising at Plymouth from the anterior slope of crest No. 2, and it continued rising until the 7th, when the crest passed. At Christiania the barometer had fallen from the posterior slope of crest No. 2. It appears from a careful comparison and consideration of the barometric movements at Plymouth and Christiania, that crest No. 2 passed Christiania about a day earlier than it did Plymouth, that is, the longitudinal direction of the crest was such as to cause it to pass over Christiania while Plymouth was still under the anterior slope of the wave, the sections passing over Christiania and Plymouth being separate and distinct. The character of the passing wave is well-determined at both stations, the posterior slope exhibiting a rapid and deep fall, which took place alike at Christiania and Plymouth.

The crest No. 2 passed Cork, Belfast and the Orkneys on the 5th, Plymouth on the 7th, and Paris on the 8th, with a diminution of oscillation. We find however no diminution of oscillation at Christiania as compared with Plymouth. It is highly probable, the subsidence of the crest, as it proceeded towards Paris, resulted from the influence of the land in England, while both at Plymouth and Christiania the crest was but slightly interfered with by the influence of land, the difference of level resulting from the anterior slope of crest No. 3.

These considerations exhibit a large wave of considerable breadth and slow motion, extending in a longitudinal direction from the extreme south-west of England towards the Swedish capital.

Nov. 10.—Mr. Brown's diagram for this day very distinctly and beautifully exhibits the change of currents resulting from the transit of crest No. 3, as well as from the progress of the posterior trough of crest No. 2. The trough of the latter wave is now between the Orkneys and Paris (the deep trough before mentioned), the wind in the south-eastern portion of the diagram is S.W., the strength increasing towards the *trough*. At Thurso and North Shields the wind is N.W., the anterior slope of crest No. 3; in the south-west of Ireland, the wind is S.E. (posterior slope). The N.E. wind on the anterior slope of the wave succeeding crest No. 2 is seen on the north-west side of the trough.

November 11, 1842.

Crest No. 2.

S.W.——————N.E.

Crest No. 3.

N.W.——————S.E.

Max.	Christiania	29·48	Crest No. 3.
	Paris	29·25	Under posterior slope of Crest No. 2.
	London	29·00	
	Plymouth	29·12	In the neighbourhood of posterior trough, Crest No. 2.
	Bristol	29·03	
	Shields	28·99*	
	Cork	28·91†	Posterior trough, Crest No. 3.
	Belfast	29·02	Under anterior slope of wave succeeding Crest No. 2 and posterior slope of Crest No. 3.
	Orkneys	29·24	
Max.	Christiania	29·48	Under posterior slope, No. 3.
	Orkneys	29·24	
	Belfast	29·02	
	Shields	28·99	
	Cork	28·91	
	London	29·00	Under posterior slope, No. 2.
	Paris	29·25	
	Plymouth	29·12	
	Bristol	29·03	
	Cork	28·91	

Slopes.—Lines of greatest diminution of pressure.

On posterior slope of Crest No. 3. Christiania to Cork.. ·57

On posterior slope of Crest No 2. Paris to Cork ..... ·34

Currents.—Wind on N.W. side of Crest No. 2, S.W.

„ S.W. „ „ 3, S.E.

* Depressed by posterior trough of Crest No. 2.

† Depressed by posterior trough of Crest No. 3.

The progressive motion of the two posterior slopes is very discernible. Crest No. 3 has passed the Orkneys and arrived at Christiania seven days after crest No. 1 passed that station. We found an interval between the crests as they passed the central parts of England of nine days. Most probably a discussion of observations at shorter intervals and more numerous stations, especially to the north-east of Christiania, would explain the discrepancy. The difference in level is very much greater than that which characterized the transits of the crests over the centre of England, but in the interval between the crests passing England and Sweden, the deep trough of crest No. 2 has advanced, which must very considerably have depressed the crest at Christiania, as compared with the English stations; indeed so great was the depressing influence of the wave, crest No. 2, that no rise is recorded as crest No. 3 passed Plymouth.

Crest No. 2 is situated considerably to the south-east of Paris, so that its progress is not perceptible on the area; but that of its posterior slope is very clear. On the 9th, the deep posterior trough of this wave passed the Orkneys with a depression of 28·80; (bearing in mind that its direction was S.W.—N.E.) another section passed Christiania on the 10th, 29·24; and a third passed Plymouth on the 11th, 29·12.

Symmetrical Wave.—On this day the great symmetrical wave commenced at London; the position of this station was nearly similar under both slopes.

November 12, 1842.

Crest No. 3.

N.W.——————S.E.

Crest No. 5.

N.W.——————S.E.

	Christiania	29·20	Under posterior slope, No. 3.
	Orkneys	29·10	
Min.	Shields.....	29·07	
			Trough.
	Belfast.....	29·21	Under anterior slope, No. 5.
	Cork	29·31	
	Bristol.....	29·31	
	London	29·33	
	Paris	29·43	
Max.	Plymouth	29·46	

Slopes.—Lines of greatest diminution of pressure.

On posterior slope of Crest No. 3. Christiania to Shields.. ·13

On anterior slope of Crest No. 5. Plymouth to Shields.... ·89

Currents.—Wind on S.W. side of trough, N.W.

A few stations exhibit a S.W. wind on the posterior slope of Crest No. 2.

The receding posterior slope of crest No 3, the intervening trough, and the approaching anterior slope of crest No. 5, are brought fully into view this day; the wind also is in close accordance with the transit of these waves. The wave (crest No. 3) appears to be much smaller than that of No. 1; the interval between the crests, as passing the centre of England, was found to be nine days; the epoch of the passage of the intervening trough occurred on November 7; interval between the troughs five days, taking the last interval as the amplitude in time of the wave; it is clearly much smaller than the preceding.

Symmetrical Wave.—London is situated under and rising from the anterior slope of wave No. 5.

November 13, 1842.

Crest No. 2.

S.W.——————N.E.

Crest No. 5.

N.W.——————S.E.

Anterior slope, Crest No. 5.

Max.	Paris	29·53	London.....	29·26
	Plymouth ..	29·46	Shields	29·24
	Cork	29·40	Orkneys	29·35
	Belfast	29·27	Christiania ..	28·94

Slope.—Line of greatest diminution of pressure.
Anterior slope, Crest No. 5. Paris to Christiania.. ·59.
Trough succeeding Crest No. 2. Between Paris and Orkneys.
Trough between Crests Nos. 3 and 5 now transits Christiania.
Currents.—Wind on S.E. side of trough No. 2, S.W.
„ N.W. „ „ „ „ N.E.

The anterior slope of crest No. 5, the third wave of the S.W. system, is well-developed; but the prevailing winds are those due to the S.E. and N.W. sides of the trough succeeding crest No. 2.

It appears from a consideration of the continuation of the tables appended to Nov. 8, that one or two small waves rode in the trough succeeding crest No. 2, which entered on the area on the 9th, and most probably traversed it during the next four days, presenting the same slowness of motion as the crest itself.

Symmetrical Wave.—London is situated under the anterior slope of crest No. 5 and the posterior slope of crest No. 2, and falling either from the latter slope or the posterior slope of one of the small waves riding in the deep trough.

November 14, 1842.

Crest No. 5.

N.W.——————S.E.

Crest No. 4.

S.W.——————N.E.

Max.	Belfast	29·91	Near the Crest No. 5.
	Shields	29·82	
	London.....	29·80	
	Orkneys	29·76	Under anterior slope, No. 5.
	Christiania.....	29·35	
	Plymouth	29·68	Under posterior slope, No. 5.
	Paris	29·67	
	Bristol	29·65	
	Cork	29·60	

Slope.—Line of greatest diminution of pressure.
Anterior slope, Crest No. 5. Belfast to Christiania.. ·56.
Currents.—Wind on advancing slope of Crest No. 4, N.E.
„ N.E. side „ „ 5, N.W.
„ S.W. „ „ „ 5, S.E.

The crest No. 5 now passes over Great Britain and Ireland much in the same direction as the crests Nos. 1 and 3 (compare Nov. 1 and 10). Its altitude is about ·25 higher than that of the last S.W. crest; the adva slope of the second N.W. wave has approached, raising the present c

Symmetrical Wave.—The crest No. 5 forms the second subordinate maximum on the anterior slope of the great symmetrical wave (see plate 2 appended to Sir J. Herschel's Report, 1843, and plate 3, illustrating the volume of Reports, 1845). The first strongly developed rise and fall on the anterior slope of the symmetrical wave appears to be a small wave riding in the trough (A^3).

It appears highly probable that the large wave from the N.W. possessed both a broad crest and broad trough, with a very slow progressive motion. The anterior slope of crest No. 4 appears to have commenced riding over Christiania on the 10th.

November 15, 1842.

Crest No. 5.

N.W.——————S.E.

Crest No. 4.

S.W.——————N.E.

Anterior slope, Crest No. 5.		Posterior slope, Crest No. 5.	
Max. Orkneys....	30·01	Max. Orkneys....	30·01
Christiania..	29·70	Shields	29·83
		Belfast	29·82
		Plymouth ..	29·64
		London....	29·62
		Bristol	29·61
		Paris.....	29·55
		Cork	29·37

Slope.—Line of the greatest diminution of pressure.

Posterior slope, Crest No. 5. Orkneys to Cork.. ·64

Currents.—Wind on anterior slope of Crest No. 4, N.E.

„ posterior „ „ 5, S.E.

The southern coasts of England exhibit a S.W. wind.

The progression of the crest No. 5 in the same direction as crest No. 1 (see Nov. 2), is very discernible; there can be no doubt of its being a wave of the same system.

Symmetrical Wave.—The barometer at London has fallen from the posterior slope of No. 5, but the anterior slope of No. 4 is gently raising it.

November 16, 1842.

Crest No. 5.

N.W.——————S.E.

Crest No. 4.

S.W.——————N.E.

Anterior slope, Crest No. 5?		Anterior slope, Crest No. 4.	
Max. Orkneys....	30·22	Max. Orkneys....	30·22
Christiania..	29·86	Belfast	30·06
		Shields	30·03
		London....	29·79
		Bristol	29·78
		Plymouth ..	29·70
		Cork	29·70
		Paris.....	29·50

Slope.—Line of greatest diminution of pressure.

Anterior slope, Crest No. 4. Orkneys to Paris.. ·72

Currents.—The winds this day appear to be those due to the anterior slope of crest No. 4, or resultants of that and the posterior slope of crest No. 5.

The posterior slope of crest No. 5 is well and strikingly developed, and the advancing slope of crest No. 4, the succeeding wave to that of No. 2, is indicated by the line of greatest pressure, Orkneys to Paris, ·72 (see Nov. 2, when the first wave from the N.W. was coming up).

Symmetrical Wave.—London is situated under the posterior slope of crest No. 5 and anterior slope of crest No. 4, and slightly rising from the latter.

November 17, 1842.

Crest No. 7.

N.W.——————S.E.

Crest No. 4.

S.W.——————N.E.

Anterior slope, Crest No. 4.			Anterior slope, Crest No. 7.		
Max.	Belfast	30·51	Max.	Belfast	30·51
	Shields	30·45		Orkneys....	30·35
	Bristol	30·36		Christiania..	29·94
	Plymouth ..	30·36	Posterior slope, Crest No. 7.		
	London	30·36	Max.	Belfast	30·51
	Paris	29·99		Cork	30·31

Slopes.—Lines of greatest diminution of pressure.

Belfast to Paris..... ·52

Belfast to Christiania .. ·57

Currents.—Wind on anterior slope of Crest No. 4, N.E.

„ posterior „ „ „ 7, S.E.

In the south-west of Ireland and England the wind is easterly, being the resultant of these forces.

The anterior slope of crest No. 4, extending from Belfast to Paris, is well-developed with its proper wind N.E. This anterior slope may be advantageously compared with the anterior slope of crest No. 2, which occupied the same area on the 5th (interval twelve days). The altitude on that occasion from Paris to Belfast was equal to ·80, on the present it is only equal to ·52. This may to a certain extent be explained by the presence of crest No. 7, which this day passes over Belfast, so that this crest elevates the anterior slope of No. 4. The anterior slope of crest No. 7 is well-developed towards the Orkneys and Christiania, and the diminution of pressure resulting from the posterior slope is conspicuous at Cork; we have consequently two crests traversing the area and *crossing* each other at Belfast.

Crest No. 4 passes the Orkneys, Belfast, Shields and Cork this day.

Symmetrical Wave.—London is situated nearly under the crest of No. 7 and under the anterior slope of crest No. 4, and rising from the latter.

November 18, 1842.

Crest No. 7.

N.W.——————S.E.

Crest No. 4.

S.W.——————N.E.

Transit of the Crest of the Great Symmetrical Wave.

Anterior slope, Crest No. 4.			Crest No. 4.		
Max.	London	30·53	Max.	London	30·53
	Paris	30·38		Plymouth ..	30·47
				Bristol	30·42
				Shields	30·42
				Christiania..	30·11

Posterior slope, Crest No. 4.		Anterior slope, Crest No. 7.	
Max. London....	30·53	Max. London	30·53
Shields	30·42	Christiania..	30·11
Belfast	30·37		
Cork	30·18		
Orkneys ..	30·18		

Slopes.—Lines of greatest diminution of pressure.

Posterior slope, Crest No. 4. London to Cork ..... ·35
" " " " 4. " Orkneys.... ·35
Anterior slope, Crest No. 7. " Christiania.. ·42

Currents.—Wind on posterior slope of Crest No. 4, S.W.

A few S.E. directions indicating the posterior slope of Crest No. 7.

The crest No. 4 has advanced with considerable rapidity as compared with No. 2. It now passes London. The depressions to Cork and the Orkneys are equal; these lines are on the posterior slope; the crest No. 7 rises between the stations. This crest appears to have a very slow motion; its anterior slope is well-seen in the diminution of pressure from London to Christiania,=·42.

Crests Nos. 4 and 7 cross at London.

Symmetrical Wave.—The crest passes over London; it is identical with the crest No. 4.

November 19, 1842.

Crest No. 7.
N.W.——————S.E.

Crest No. 9.
N.W.——————S.E.

Crest No. 4.
S.W.——————N.E.

Max.	Paris	30·17	Under anterior slope, Crest No. 9.
	Plymouth ..	30·14	
	London	30·06	Under anterior slope, Crest No. 9, at a lower level.
	Bristol	29·98	
	Cork	29·92	
	Belfast	29·86	Near the trough between 9 and 7.
Min.	Shields	29·77	
	Orkneys....	29·91	Under posterior slope, Crest No. 7.
	Christiania..	29·91	

Slopes.—Line of greatest diminution of pressure.
Paris to Shields.... ·40

Currents.—Wind on posterior slope, No. 4, S.W.
" " " " 7, S.E.

Symmetrical Wave.—London is situated under the posterior slope of crest No. 4 and anterior slope of crest No. 9, not far removed from the preceding trough.

The crest No. 4 has now passed considerably to the S.E. of Paris, which exhibits the greatest pressure; the posterior slope extends in the direction towards Belfast, although Shields is the minimum point. The trough between crests 7 and 9 passes somewhat near Belfast and Shields.

November 20, 1842.

Crest No. 9.

N.W.——————————S.E.

Crest No. 6.

S.W.——————————N.E.

Anterior slope, Crest No. 6.			Anterior slope, Crest No. 9.		
Max.	Orkneys....	29·96	Max.	Orkneys....	29·96
	Belfast	29·91		Christiania..	29·60
	Cork	29·80			
	Shields	29·85			
	London	29·77			
	Plymouth ..	29·73			
	Paris	29·55			

Slope.—Line of greatest diminution of pressure.
Anterior slope, Crest No. 6. Orkneys to Paris .. ·41
Currents.—Wind on anterior slope of Crest No. 6, N.E.
„ posterior „ „ „ 9, S.E. and E.

The observations of this day, both barometric and anemonal, indicate the presence of an anterior slope of a wave succeeding crest No. 4 of the N.W. system. Crest No. 9 now passes over the Orkneys and between Christiania and Paris.

Symmetrical Wave, two days after transit.—London is situated under the anterior slope of crest No. 6 and posterior slope of crest No. 9.

On the 16th, two days before transit, London was similarly situated with respect to waves Nos. 4 and *5*, with nearly the same barometric pressure.

On the 13th a permanent rise took place at London, which continued until crest No. 4 passed the station. It appears that this should be carefully distinguished from the rise and fall of the 16th to 19th, the latter being due to a separate and distinct wave.

The curve from noon of the 16th to midnight of the 19th appears to represent the form of the N.W. wave riding on the top or superposed on the normal or great symmetrical wave.

November 21, 1842.

Crest No. 11.

N.W.——————————S.E.

Crest No. 6.

S.W.——————————N.E.

Crest No. 11.			
Max.	Belfast	29·95	Near the crest.
	Shields	29·89	
Max.	Belfast	29·95	Under anterior slope.
	Orkneys....	29·86	
Min.	Christiania..	29·54	
Max.	Belfast	29·95	Under posterior slope.
	Cork	29·83	
Crest No. 6.			
Max.	Belfast	29·95	All under the anterior slope at different levels.
	Cork	29·83	
	Shields	29·89	
	Bristol	29·79	
	Plymouth ..	29·79	
	London	29·82	
Min.	Paris	29·57	

Slopes.—Lines of greatest diminution of pressure.
Anterior slope of Crest No. 11. Belfast to Christiania .. ·41*
Anterior slope of Crest No. 6. Belfast to Paris ..... ·38
Currents.—Wind on anterior slope of Crest No. 6, N.E.
„ posterior „ „ „ 11, E.S.E.

Another S.W. wave now transits the area, and the crest of No. 6 is rapidly approaching.

Symmetrical Wave, three days after transit.—London is situated under the anterior slope of No. 6 and posterior slope of No. 11, and slightly rising from the former.

On the 15th, three days before transit, London was similarly situated with respect to waves 5 and 4.

November 22, 1842.

Crest No. 11.
N.W.——————S.E.
Crest No. 13.
N.W.——————S.E.
Crest No. 6.
S.W.——————N.E.

Max.	Cork	29·58	
	Belfast	29·42	
	Orkneys	29·43	All under the anterior slope of
	Plymouth ..	29·53	crest No. 6. The trough between
	Bristol	29·39	No. 11 and 13 is seen at Belfast
	Shields	29·30	and Shields, the stations being ar-
	Christiania ..	29·55	ranged to exhibit this.
	London	29·28	
	Paris	29·13	

Slopes.—Lines of greatest diminution of pressure.
Anterior slope, Crest No. 6. Cork to Paris ..... ·45
Posterior slope, Crest No. 9. Christiania to Paris.. ·42
Currents.—Wind on S.W. side of trough between crests 11 and 13, N.W.
A few S.W. directions as Crest No. 6 passes.

The anterior slope of crest No. 6 is still strikingly developed from Cork to Paris; the trough between crests 11 and 13 extends in the direction of Belfast and Shields.

Symmetrical Wave, four days after transit.—London is situated under the anterior slopes of crests Nos. 6 and 13. The barometer has fallen from the posterior slope of crest No. 11.

November 23, 1842.

Crest No. 13.
N.W.——————S.E.
Crest No. 6.
S.W.——————N.E.

Max.	Christiania ..	29·62	
	London	29·59	Under anterior slope, Crest No. 6.
	Paris	29·41	

* From a comparison of the St. Petersburg observations, it appears that wave, crest No. 11, was a small wave, and that the diminution of pressure, Belfast to Christiania, was compounded of the anterior slopes of crests 9 and 11, that of 11 being very small. See Postscript.

London	29·59	Under posterior slope, Crest No. 6.
Plymouth ..	29·30	
Bristol	29·26	
Shields	29·27	
Cork	29·10	Under posterior slope, Crest No. 6, at a lower level.
Belfast	29·32	
Orkneys....	29·33	

Slopes.—Lines of greatest diminution of pressure.

Posterior slope of Crest No. 13. Christiania to Cork.... ·52

Posterior slope of Crest, No. 6. London to Cork ..... ·49

A trough between crests No. 13 and 15 extends in the direction of Cork and Bristol*.

Currents.—Wind on S.W. side of this trough, N.W.

„ N.W. „ Crest No. 6, S.W.

Crest No. 6, the third of the N.W. system, now passes London five days after the transit of crest No. 4, the second of this system. Christiania at this time exhibits the greatest pressure; most probably the crest No. 13 is approaching this station, and this, combined with crest No. 6, produces the increased pressure. At the transit of crest No. 4 Christiania exhibited the least pressure; the difference may probably be explained by the transits of the cross waves.

Symmetrical Wave.—London is situated under the crest of No. 6, not far removed from the trough, between crests 13 and 15.

November 24, 1842.

Crest No. 13.

N.W.——————S.E.

Crest No. 6.

S.W.——————N.E.

Max.	Christiania..	29·66	All except Christiania under posterior slope of Crest No. 6.
	Paris	29·02	
	London	28·92	
	Plymouth ..	28·91	
	Bristol	28·79	
	Shields	28·78	
	Cork	28·54	
	Belfast	28·79	
	Orkneys....	29·10	
Max.	Christiania..	29·66	Under posterior slope, No. 13.
	Orkneys....	29·10	
	Belfast	28·79	
	Shields	28·78	
	Cork	28·54	
	London	28·92	

* The barometric fall between the 21st and 23rd, that occurred at all the stations except one, appears to have given rise to an apparent *regression* of the trough observed in the neighbourhood of Belfast and Shields on the 22nd. It was shown that on the 22nd the anterior slope of crest No. 6 was coming up from the N.W., so that the fall of the 21st resulted from the posterior slope of crest No. 9. On the 23rd the crest No. 6 passes London, and we have at some stations a much more sudden fall than resulted from the passage of the posterior slope of crest No. 9. We may therefore regard the trough in the direction of Cork and Bristol as an indication of the approaching trough of crest No. 6, rather than a new trough between 13 and 15. Should this view be correct, the line of greatest diminution of pressure, Christiania to Cork, will be on the posterior slope of crest No. 9.

Paris	29·02	Under posterior slope, No. 6.
Plymouth ..	28·91	
Bristol	28·79	
Cork	28·54	

Slopes.—Lines of greatest diminution of pressure.

Christiania to Cork.... 1·12. Slope, No. 13.
Paris „ „ .... ·48. „ „ 6.

Currents.—Wind on posterior slope of Crest No. 6, S.W.
„ „ „ „ „ 13, S.E.

East in the north of Scotland and the Orkneys.

The progressive motions of the two slopes are well-seen from the observations of this day, which may be very advantageously compared with those of the 11th, when the movements were similar; crest No. 13 has advanced to Christiania with the succeeding trough; crest No. 6 has advanced to or beyond Paris.

Symmetrical Wave.—London is situated under the posterior slope of crest No. 6, not far removed from and to the S.W. of the posterior trough of crest No. 13.

November 25, 1842.

Crest No. 13.

N.W.——————S.E.

Crest No. 6.

S.W.——————N.E.

Max.	Christiania..	29·62	Most probably all under the posterior slope of Crest No. 6.
	Paris	29·01	
	London....	28·88	
	Plymouth ..	28·93	
	Bristol	28·84	
	Shields	28·82	
	Cork	28·80	
	Belfast	28·82	
	Orkneys....	29·07	
Max.	Christiania..	29·62	Under posterior slope, No. 13.
	Orkneys....	29·07	
	Belfast	28·82	
	Shields	28·82	
	Cork	28·80	
	London....	28·88	
	Paris	29·01	Under posterior slope, No. 6.
	Plymouth ..	28·93	
	Bristol	28·84	
	Cork	28·80	

Slope.—Lines of greatest diminution of pressure.

Posterior slope, No. 13. Christiania to Cork.. ·82
Posterior slope, No. 6. Paris to Cork ..... ·21

Currents.—Wind on posterior slope of Crest No. 6, S.W.
„ „ „ „ „ 13, S.E.S.
„ anterior „ „ „ 15, N.W.

The barometric state of the atmosphere much the same as yesterday; the greatest difference occurs at Cork, most probably from the advancing slope of the wave, crest No. 15. The wind is closely in accordance with the wave slopes.

November 26, 1842.

Crest No. 13.

N.W.——————————S.E.

Crest No. 6.

S.W.——————————N.E.

Crest No. 15.

N.W.——————————S.E.

Max.	Christiania..	29·57	Under posterior slope, No. 13.
	Orkneys....	29·10	
Min.	Shields	28·99	Trough.
	Belfast	29·04	Under anterior slope, No. 15.
	Cork	29·04	
	Bristol	29·14	
	London....	29·17	
	Paris	29·17	
	Plymouth ..	29·20	
	Paris	29·17	Under posterior slope, No. 6.
	London	29·17	
	Bristol	29·14	
	Belfast	29·04	
	Cork	29·04	

Slopes.—Lines of greatest diminution of pressure.

Posterior slope, No. 13.	Christiania to Shields ..	·58
„ „ „ 6.	Paris to Cork	·13
Anterior „ „ 15.	Plymouth to Belfast	·16

Currents.—Wind on posterior slope of Crest No. 6, S.W.

„ „ „ „ „ 15, N.W.

The advance of the anterior slope of crest No. 15 is well-seen from the observations of this day. The wind proper to it, N.W., has increased in the S.W. portion of the area. It appears that the motion of the waves—crests Nos. 13 and 15 with the included trough—is *slower* than that of the waves, crests Nos. 3 and 5 (see Nov. 11 and 12). The same arrangement of stations as to the distribution of pressure which required only *one* day to establish in the case of waves 3 and 5, has occupied *two* days in the case of waves 13 and 15. The distribution of pressure was similar on the 11th and 24th; it was also similar on the 12th and 26th.

Section III.

Results of the foregoing Discussion.

In collecting the results of this discussion, I have arranged in Tables XI. and XII. the principal lines of diminution of pressure; the succession of waves as well as the distinct systems become very apparent from these tables. The succeeding Tables XIII. and XIV. exhibit the principal features of the respective waves of each system. The most prominent result appears to be the confirmation of Prof. Dove's suggestion of parallel and oppositely directed currents. The diagrams of the wind in connection with the barometric observations clearly exhibit such currents, and we see by a glance at Tables XIII. and XIV. that the beds of these currents varied considerably in breadth. At the opening of the observations they were very much *broader* than at the close, and the N.W. system (waves No. 2, 4, 6) were altogether larger than the S.W. We have in fact two systems of waves or currents crossing each

other at right angles, the individuals in both gradually decreasing in size. In the speculation which has been ventured relative to the S.W. system, the mass of terrestrial surface forming the N.W. boundary of the great eastern continent has been assumed as the rarefying surface, producing the set of parallel and oppositely directed S.E. and N.W. winds, the currents gradually shifting towards the N.E. The gradual contraction of the beds of each system as the observations proceed is a highly interesting feature, which requires a more extensive discussion for its elucidation.

TABLE XI.—Exhibiting the principal lines of the greatest diminution of pressure of the N.W. system of waves, Nos. 2, 4, and 6.

Epochs.	Directions.	Values.	Slopes.
Nov. 1	Belfast to Paris	·29	Anterior, No. 2
2	Orkneys to Paris.....	·37	2
4	Orkneys to Paris.....	·69	2
5	Belfast to Paris	·80	2
6	Belfast to Paris	·68	2
7	Belfast to Paris	·54	2
9	Paris to Orkneys.....	·96	Posterior, No. 2
10	London to Cork	·44	2
11	Paris to Cork	·34	2
16	Orkneys to Paris.....	·72	Anterior, No. 4
17	Belfast to Paris.	·52	4
18	London to Cork	·35	Posterior, No. 4
18	London to Orkneys.....	·35	4
20	Orkneys to Paris.....	·41	Anterior, No. 6
21	Belfast to Paris	·38	6
22	Cork to Paris	·45	6
24	Paris to Cork	·48	Posterior, No. 6
25	Paris to Cork	·21	6
26	Paris to Cork	·13	6

TABLE XII.—Exhibiting the principal lines of the greatest diminution of pressure of the S.W. system of waves, Nos. 1, 3, 5, 7, 9, 11, 13, 15.

Epochs.	Directions.	Values.	Slopes.
Nov. 1	Belfast to Christiania...	·55	Anterior, No. 1
3	Christiania to Paris.....	·58	Posterior, No. 1
11	Christiania to Cork.....	·57	3
12	Christiania to Shields...	·13	3
12	Plymouth to Shields ...	·39	Anterior, No. 5
13	Paris to Christiania.....	·59	5
14	Belfast to Christiania...	·56	5
15	Orkneys to Cork.....	·64	Posterior, No. 5
17	Belfast to Christiania ...	·57	Anterior, No. 7
18	London to Christiania...	·42	7
21	Belfast to Christiania...	·41	Anterior, No. 11
23	Christiania to Cork.....	·52	Posterior, No. 13
24	Christiania to Cork.....	1·12	13

TABLE XIII.—Exhibiting the principal features of the waves of the N.W. system Nos. 2, 4, and 6.

Wave No. 2.

Epochs.	Phases.	Directions and Localities.	Altitudes.	Winds. Anterior Slope.	Winds. Posterior Slope.
Nov. 1	Crest.	N.W. of the United Kingdom			
2	Crest.	N.W. of the United Kingdom	...	N.E.	
3	Crest.	N.W. of the United Kingdom	...	N.E.	
4	Crest.	N.W. of the United Kingdom	30·49+	N.E.	
5	Crest.	From Cork to the Orkneys	30·55	N.E.	
6	Crest.	S.E. of Belfast	30·51+	N.E.	
7	Crest.	S.E. of the Orkneys	30·43+	N.E.	S.W.
8	Crest.	Passes Plymouth.....	30·13		
9	Crest.	S.E. of Paris	29·90+		S.W.
9	Post. Trough.	Passes the Orkneys.....	28·80		S.W.
10	Post. Trough.	Near the eastern coast of Ireland extending to Christiania.....	29·24		S.W.
11	Crest.	Considerably S.E. of Paris.....			
11	Post. Trough.	Passes Plymouth.....	29·12		S.W.
		Wave No. 4.			
Nov. 17	Crest.	Passes Belfast.....	30·51	N.E. E.	
18	Crest.	Passes London	30·53	N.E.	S.W.
19	Crest.	Considerably S.E. of Paris.....			
		Wave No. 6.			
Nov. 21	Crest.	N.W. of Belfast and Cork	.....	N.E.	
22	Crest.	Near Cork, Belfast and Orkneys.....	29·58		
23	Crest.	Passes London	29·59		S.W.
24	Crest.	Near to or S.E. of Paris.....	.....		S.W.

TABLE XIV.—Exhibiting the principal features of the waves of the S.W. system Nos. 1, 3, 5, 7, 9, 11, and 13.

Wave No. 1.

Epochs.	Phases.	Directions and Localities.	Altitudes.	Winds. Anterior Slope.	Winds. Posterior Slope.
Nov. 1	Crest.	Belfast to Paris	30·33	N.W.	S.E.
2	Crest.	Between Belfast and Christiania ...	30·23+	N.N.W.	S.E.
3	Crest.	W. or S.W. of Christiania	30·31+	N.W.	S.E.
7	Post. Trough.	N.E. of Belfast and Paris			
		Wave No. 3.			
Nov. 7	Ant. Trough.	N.E. of Belfast and Paris			
8	Crest.	S.W. of Belfast and London	.....	N.W.	
10	Crest.	Belfast to Paris	29·64	N.W.	S.E.
11	Crest.	Near Christiania.....	29·48		S.E.
12	Post. Trough.	Between Belfast and Shields.....			

TABLE XIV. (*continued*).

Wave No. 5.

Epochs.	Phases.	Directions and Localities.	Altitudes.	Winds.	
				Anterior Slope.	Posterior Slope.
Nov. 12	Ant. Trough.	Between Belfast and Shields.....			
13	Crest.	S.W. of Cork, Plymouth and Paris...			
14	Crest.	Belfast to London	29·91	N.W.	S.E.
15	Crest.	Passes the Orkneys.....	30·01		S.E.
16	Crest.	Between Orkneys and Christiania...			E.[b]
		Wave No. 7.			
Nov. 17	Crest.	Passes Belfast	30·51		S.E. E.[b]
18	Crest.	Between Cork and the Orkneys.....			
19	Post. Trough.	Near Belfast and Shields			S.E.
		Wave No. 9.			
Nov. 19	Ant. Trough.	Near Belfast and Shields			
20	Crest.	Passes the Orkneys.....	29·96		S.E.
		Wave No. 11.			
Nov. 21	Crest.	Near Belfast and Shields	29·95	N.W.	S.E. E.[b]
22	Post. Trough.	Near Belfast and Shields			
		Wave No. 13.			
Nov. 23	Crest.	S.W. of Christiania.....	29·62		
	Post. Trough.	Cork to Bristol			

[b] Resultants of N.E. and S.E. currents.

PART III.—*Desiderata.*

In addition to briefly reviewing the progress made in this inquiry, it may be well to glance at the desiderata that now present themselves to our notice. The object of this report, in connection with the preceding ones, has been to show that we have observed on some occasions the successive returns of extensive barometric undulations, that these undulations have exhibited a certain physiognomy, and that we have been able to recognize and characterize them; that when these undulations have been observed at various and distant stations, and the observations carefully reduced and compared, they have been resolved into separate and distinct waves of pressure, each having an advancing front, a crest extending in a certain direction, a receding posterior slope, and bounded by an anterior and a posterior trough. It is the object of the second part of this report particularly to show that these characteristic features of a wave are intimately connected with a certain arrangement of the aërial currents first suggested by Prof. Dove, consisting of horizontal and parallel beds of oppositely directed winds. In his letter to Col. Sabine, the Professor speaks of these currents as northerly and southerly, the mean direction being converted into south-westerly in the northern hemisphere by the rotation of the earth. The examination of Mr. Brown's data has clearly developed a set of parallel and opposite currents at right angles to these,

namely, from N.W. and S.E.; and it has been suggested that these two sets of oppositely directed currents, N.E.—S.W. and N.W.—S.E., continually crossing each other, occasion the complexity of the barometric and anemometric phænomena, and that in future discussions these should be particularly taken into account. Should the views thus advanced be substantiated, we are beginning to unravel some of the complicated problems of meteorological research: still much remains to be done; we are as yet only on the threshhold of the vast meteorological arena now opening upon us. The subject, overwhelming with interest, naturally divides itself into two branches. First, the determination of the *phases* of the larger undulations,—the barometric curves which include *complete* elevations and depressions of the barometer, and which represent, and are exponents of, the effects resulting from contemporaneous transits of waves or systems of waves such as have been previously noticed. These, with the smaller secondary waves superposed on their slopes, form the *types* of the various seasons of the year. Second, the absolute extent of each normal wave of each system in space, as it exists with the smaller superposed waves riding on its slopes. The direction of its crest, its amplitude in miles, the altitude of its crest above, and the depression of its troughs below the surface of general repose of the atmosphere, the place of its formation, the manner in which it is propagated, the precise direction and extent of its motion, the force with which it is translated from place to place, and the locality of its final extinction, are questions which the present state of our knowledge is inadequate to resolve.

These desiderata regarding the waves as resulting from parallel and oppositely directed currents, may be thus expressed. The absolute extent, both as regards length and breadth of each current with that of its counter and oppositely directed current, together forming the two slopes of the wave with its included trough; the points or lines of intersection of the two systems of parallel and oppositely directed currents; the precise direction of the conterminous edges of the currents, the lines in which the velocity of the wind is greatest answering to the included trough; the amount of the diminution of pressure resulting from this velocity below the mean pressure of the atmosphere; the locality of the formation of these currents; the direction in which they advance with a lateral motion; the force with which they are translated by means of such lateral motion from place to place, and the locality of their final extinction or disappearance.

With respect to the first branch of inquiry, the *phases* of the larger undulations, the *seasonal* barometric *types*, but little has yet been done towards its accomplishment. There is some hope, as mentioned in the foregoing remarks, that we have obtained the type of *fourteen* days in November for *one* locality *only*; and we have also a glimpse of the character of the movements during a portion of October. This is however very small compared with the extent of the problem. At the utmost it will only amount to the twelfth part of the annual type; even the 24th cannot yet be said to be fully established. Again, the station of observation is to be taken into account; were the entire year's observations for one station projected, and year after year such observations compared, we should only have the annual type at *that* station. The examination of the symmetrical wave of 1842 has already shown that there is a line of greatest symmetry as far as that wave is concerned, namely Dublin, Birmingham, Brussels and Munich; and the discussion of the equinoctial and solstitial observations, 1835 to 1838, has clearly established Brussels as a nodal point, and we find it situated on this line of greatest symmetry. At very short distances N.E. and S.W. of the line of greatest symmetry of 1842, the symmetry is departed from. On the return of the great wave in the autumn of 1845, the line of greatest symmetry appears to

have been confined to the southern shores of England: Brussels is not far removed from this line; so that while the symmetry on the last return is considerably departed from at Dublin, it is highly probable that at Brussels the movements are more in accordance with its nodal character. It is therefore important for the complete determination of the problem, not only to obtain the annual type at one station; we also require it at numerous stations; and we ought to be furnished with local types similar to those, but more extensive, which Sir John Herschel has established for different stations from the observations of 1835 to 1838.

It has already been observed that the barometric curves at any one station do not give sections of waves passing the station, that is, the curve as projected is *not* a section of the wave then transiting, but exhibits the effects of two or more systems of waves passing at the same time. Now as like causes produce like effects, it is highly probable that there may be a general flowing of the larger normal waves in the same direction, about the same season of the year; and as we have seen in the case of the symmetrical wave that the secondary waves are erratic, sometimes falling on one point and sometimes on another of the normal waves, these normal waves may be crossed at these seasons by similar systems of secondary waves slightly removed from a normal epoch year after year, giving rise to a similarity, within certain limits, between the combined barometric curves as observed at the stations. These combined curves furnish us with the local and annual types.

While this labour is accomplishing, and we are in progress of obtaining annual and local types, we may be accumulating information that will bear considerably on the second branch of our inquiry. At present we are unable to answer these questions fully. We have obtained some glimpses of the vast extent of these waves, and in our contemplation of them we must, as Sir John Herschel beautifully observes, enlarge our conception till in the extent of their sweep and the majestic regularity of their progress they approach in some degree to the tide waves of the ocean; still our knowledge of them is very small. The volume of any one atmospheric wave, the extent of surface it covers, indeed any particular feature we may name and which we may wish to be exhibited to us in all its details, we must still reckon among our desiderata.

In closing this report, I beg to acknowledge the valuable assistance I have received from the following public bodies and gentlemen.

To the British Government I am indebted, through the hands of the Astronomer Royal and Lieut-Col. Sabine, R.A., for the volumes of Greenwich Magnetical and Meteorological Observations for the years 1840 to 1843, and the volume of similar observations made at the Colonial Observatory, Toronto, in the years 1840, 1841 and 1842. I am also indebted to both the above-named gentlemen for the readiness with which they have furnished me with extracts from the records of their respective observatories, and for many valuable suggestions which I have received, especially from Col. Sabine.

To the Lords Commissioners of the Admiralty I am indebted for several valuable sets of observations made on board our surveying vessels, and received through Rear-Admiral Beaufort, our excellent hydrographer. To this gentleman I am peculiarly indebted for the lively interest he has taken in forwarding the inquiry, and also to the officers under whose directions the observations have been made, for the care and fidelity with which they have been executed. The names of the respective officers of Her Majesty's surveying vessels will be found in Table I.

To the Honourable the Corporation of the Trinity House, I am indebted for the ready access which has been afforded me to the records of meteorological observations kept at certain lighthouses; and I take this op-

portunity of testifying to the care and fidelity with which the observations are made daily by the lighthouse keepers. The situation of the lighthouses at which observations have been made especially to assist in this inquiry, will be found in Table I.; and I am greatly indebted to the Corporation for certain modifications in the observations at these lighthouses, which have been made at my suggestion in order that the subject should receive the fullest investigation.

To THE ROYAL SOCIETY I am indebted for several sets of observations extracted from records preserved in its archives. In connection with the Society, I may mention the kind assistance I received from the late PROFESSOR DANIELL; and I take this opportunity of recording the kindness and urbanity which he ever manifested, when applied to in reference to this or any other scientific inquiry.

To SIR JOHN F. W. HERSCHEL, BART., I am under peculiar and especial obligation: the kindness I experienced from that gentleman while engaged in discussing the quarterly observations, called for and collected by himself, demands the most lively gratitude; and I take this opportunity of acknowledging this kindness, and particularly the publication, in the report drawn up by Sir John, of the remarks which had been suggested in the course of my labours, and which I had communicated at intervals. I need scarcely mention that this report forms the foundation of all my subsequent labours, and that we must ever regard Sir John as the first individual who has given an impetus to this inquiry, and who has first trodden the field to which Prof. Forbes some years since directed the attention of meteorologists. It has been well-said by Col. Sabine, "that Sir John Herschel is the father of all our modern researches in meteorology; to him we owe all our hourly observations, and to him we are indebted for those systematic arrangements by which meteorology will take its due place among the sciences." The observation of the great symmetrical wave in November 1842, was an immediate consequence of the discussion of Sir John's hourly observations. It resulted in fact from a continuance (at such intervals as I could command) of the observations until a complete rise and fall of the barometer had been observed, and projected in a curve on a similar but reduced scale to that used in the projections of the quarterly observations. My former reports carry on the history; in them I have mentioned the further assistance I have received from Sir John, which I have now great pleasure in acknowledging.

To CAPT. LARCOM, R.E., I am indebted for a valuable series of observations, accompanied with curves during October, November, and December 1845. I have already alluded to these in the body of the report.

To PROFESSOR PHILLIPS and DR. STEVELLY I am indebted for some valuable series from the north of England and Ireland. I am also indebted to DR. LLOYD for several extracts from the records of the Dublin observatory: also to SIR THOMAS BRISBANE, PROFESSOR NICHOL and SILVANUS THOMPSON, for observations made at their respective observatories.

To PROFESSOR QUETELET I am indebted for a valuable series from the observatory at Brussels, and for several series of the quarterly observations collected by himself, which may be most advantageously used in such inquiries as the present.

To E. W. BRAYLEY, JUN., ESQ., of the LONDON INSTITUTION, I am greatly indebted for the valuable assistance which he has on several occasions in connection with this inquiry most readily afforded me; especially the great interest which he manifested at the commencement of the discussion of Sir John Herschel's quarterly observations which materially contributed to the reductions being entrusted to my hands; and I take this opportunity of acknowledging, not only such assistance, but also the direction which that gentleman has given to my earlier studies, and the advice he has offered me in prosecuting

my inquiries. The interesting conversations on this and kindred subjects that I have had with him during the last ten years, have greatly assisted me in my labours. I am also indebted to GEORGE GWILT, ESQ. and to E. JOHNSTON, ESQ., for the assistance afforded by those gentlemen, in my earliest endeavours to observe and trace a complete wave.

To the gentlemen named in the third column of Table I., I am indebted for observations at the stations recorded in the first column of that table, which have been made with great care, and mostly at the hours named in the instructions.

I cannot close this report without remarking, that many of the observations which have thus been collected and partially discussed, owe their existence entirely to the auspices of this Association; and should the further discussion of them be entrusted to my hands, the same care shall be manifested which I have endeavoured to exhibit in my previous labours; and by examining them in every point of view and under every possible aspect, I trust the result will be such as fully to accord with the great object of the Association; and should no new facts be elicited, yet it is to be hoped that these observations, called for as they have been by the Association, will confirm the suggestions, and throw considerable light on the labours of several eminent meteorologists, so that in these respects subjects at which we have only obtained a glance, may be brought fully into view, and thus by means of these observations the science in some degree advanced.

Of the grant of £7 placed at my disposal I have expended £3 3*s.* 3*d.* As nearly the whole of the observations on the return of the great wave in the autumn of 1845, as well as those during the previous October are at present unreduced, I respectfully request a continuance of the grant.

W. R. BIRT.

Postscript, April 10, 1847.

During the period between the sitting of the Association and this report passing through the press, I have been furnished, by the liberality of the Royal Society, with the magnetical and meteorological observations made during the year 1842 at various stations in the Russian empire. These stations embrace an area extending over 195 degrees of longitude. The observations at St. Petersburgh, the nearest station to those given by Mr. Brown, in a great majority of cases fully confirm the results arrived at in the preceding discussion, and in others the views obtained by means of Mr. Brown's observations are corrected, and considerable light thrown on the real character of the smaller waves traversing Great Britain and Ireland. In addition to these advantages, the Russian observations, in connexion with others, exhibit to us the vast area over which the slopes of these waves extend, so vast that they actually approach in the extent of their sweep and the regularity of their progress to the tide-waves of the ocean. But this is not all; the records of the Russian observatories contain ample materials for carrying out the suggestion of Sir John Herschel, expressed in the close of his Report on Meteorological Reductions (Report, 1843, page 98), "that when dealing with undulations of such extent, it is by no means a visionary speculation to consider the possibility of tracing them over the whole of our globe." The area embraced by Mr. Brown's and the Russian observations extends over 235 degrees of longitude; and it is apparent from the observations themselves, that the greater fluctuations are readily traceable. Our Colonial Observatory at Toronto will carry on the observations from Sitka, and the stations on the eastern shores of America will enable us to trace the waves from the eastern to the western shores of the Atlantic, over the vast continents of Europe and Asia.

The following table contains the altitude of the barometer at St. Petersburgh during the twenty-six days included by Mr. Brown's observations

Whenever the results obtained by means of Mr. Brown's observations are either confirmed or illustrated by them, a reference is made to the day on which the particular wave, as indicated by the observations given in page 141, is either identified with one as developed by my previous investigations, or more clearly exhibited and its true character more distinctly brought to light.

TABLE XV.—Barometric readings at St. Petersburgh, 1842. Nov. 1 to 26, at noon, illustrating Table V.

Date.	Eng. In.	Date.	Eng. In.	Date.	Eng. In.
Nov. 1	29·449	Nov. 10	29·890	Nov. 19	30·155
2	29·795	11	·659	20	29·866
3	30·213	12	·870	21	·776
4	·222	13	·617	22	·419
5	·251	14	·530	23	29·585
6	30·164	15	·139	24	30·032
7	29·961	16	·450	25	·060
8	·963	17	·682	26	·110
9	29·916	18	·848		

November 5. Crest No. 1.—The observations of Nov. 1 indicated a crest which passed across England and Ireland with a general direction N.W.—S.E. This crest is now vertically over St. Petersburgh. We have traced it from Belfast, past the Orkneys to Christiania, and we now find it at St. Petersburgh. The observations of this day, as given by Mr. Brown, clearly indicate the direction of crest No. 2, so that the point of intersection of the two crests, Nos. 1 and 2, must have been situated towards the north-west of Norway. This at once explains the greater amount of pressure in the north-west of Europe in the early part of November.

November 8. Posterior slope, crest No. 2.—This slope was characterized by a deep barometric fall, which was very considerable, especially at the north-western stations. A very careful comparison of Mr. Brown's observations with those made at St. Petersburgh and those given in my last report, Section III. (Report, 1845, pp. 124 to 128), identifies crest No. 2 with wave A° of the last report. The direction of the crest, from a comparison of the numbers over the larger area, including St. Petersburgh, appeared to extend from the south-west of England past Norfolk to the east of Christiania, and between this station and St. Petersburgh.

It has been observed in the remarks under the head anterior slope, crest No. 2 (page 146), that the altitude of this crest (No. 2) appears to have *subsided* as the wave progressed. This subsidence was also observed at Christiania and St. Petersburgh. At Christiania the crest passed with about the same *altitude* as it passed Plymouth, 30·27, and at St. Petersburgh it was slightly under 30 inches.

November 9. Posterior slope, crest No. 2.—On this day this posterior slope comes into full view. We have already identified crest No. 2 with wave [illegible] of my former investigations. The observations of this day give us the section of the posterior slope, which more or less accords with the sections of atmospheric pressure at 3 P.M. of this day, as exhibited in plates 45 and 46, Report 1844.

November 10. Crest No. 3.—The direction of this crest is nearly identical with that of No. 1, which passed over Great Britain and Ireland on the [illegible]. A comparison of Mr. Brown's observations with those at St. Petersburgh and those given in my last report, identifies this wave, crest No. 3, [illegible]° (see Report, 1845, page 125).

Crest No. 2.—This crest is situated to the east of St. Petersburgh on this day, at the same time that its posterior trough is situated to the east of the

Orkneys. This will give some idea of the extent of country covered by this wave and the vast amount of its amplitude. The direction of the trough is indicated on plate 42, Report, 1844.

November 11. Posterior troughs, crests Nos. 2 and 3.—On Nov. 5 we distinctly traced the directions of the crests Nos. 1 and 2, and the observations at St. Petersburgh assisted us in indicating the locality of their intersection. The observations of this day, Nov. 11, indicate the contemporaneous existence of the posterior troughs of crests Nos. 2 and 3.

It appears probable, from a consideration of the observations of November 12, that the depression which occurred at Plymouth (see page 150) was occasioned by the crossing of the posterior troughs of crests Nos. 2 and 3. If so, we are enabled to form a correct estimate of the direction of these contemporaneous troughs. The posterior trough of crest No. 2 now passes St. Petersburgh. Table IX. (Report, 1845, page 125) clearly indicates that the depression of this day, in the south of England, was due to the posterior trough of crest No. 3. We find Paris *under the posterior* slope of crest No. 2, so that the intersections of the troughs must have been situated in the neighbourhood of Plymouth, or between Cork and Plymouth: the direction of the trough of crest No. 3 appears to have extended from Paris towards Cork while the crest was passing Christiania. It appears the velocity of crest No. 3 was greater than that of crest No. 1, which may, to a certain extent, explain the discrepancy noticed in page 150.

November 12. Crest No. 3.—This crest now passes St. Petersburgh, while its posterior trough passes Belfast and Shields.

November 15. Anterior trough, crest No. 5.—This trough now transits St. Petersburgh. The fact of the succeeding crest (No. 5) passing the Orkneys at the same time, clearly indicates the wave to be much smaller than the preceding two.

November 17. Crest No. 7.—It appears from a comparison of the Christiania and St. Petersburgh observations that the wave, crest No. 7, was very small.

November 18. Crest No. 4.—This wave, which forms the crown of the great symmetrical wave, has been very distinctly developed by the discussion of Mr. Brown's observations. The altitude it attained, especially in the south-east of England, has contributed to bring it prominently into view. The observations at St. Petersburgh make us acquainted with the great extent of its longitudinal direction. Its crest passed Dublin on the 17th, London on the 18th, and Munich on the 19th (see plate 2, appended to Sir John Herschel's Report on Meteorological Reductions, Report, 1843). In the following table the transit of its crest at the three northern stations, the Orkneys, Christiania and St. Petersburgh, is readily seen. The direction in which the wave progressed being N.W. to S.E., the section which passed over St. Petersburgh was more northerly than the others. The maximum occurred at St. Petersburgh at least twelve hours later than at Munich, and about two days later than at Dublin.

TABLE XVI.

Epoch.	Orkneys.	Christiania.	St. Petersburgh.
Nov. 17	30·35[c]	29·94	29·68
18	30·18	30·11[c]	29·85
19	29·91	29·91	30·16[c]

[c] Crest.

[*For Addenda to this Report see end of the Reports.*]

UNIVERSITY OF CALIFORNIA

Report on the Archetype and Homologies of the Vertebrate Skeleton.

By Prof. Owen, *F.R.S.*

Part I.—Special Homology.

Introduction.

When the structure of organized beings began to be investigated, the parts, as they were observed, were described under names or phrases suggested by their forms, proportions, relative position, or likeness to some familiar object. Much of the nomenclature of human anatomy has thus arisen, especially that of the osseous system, which, with the rest of man's frame, was studied originally from an insulated point of view, and irrespective of any other animal structure or any common type.

So when the exigences of the veterinary surgeon, or the desire of the naturalist to penetrate beneath the superficial characters of his favourite class, led them to anatomise the lower animals, they, in like manner, seldom glanced beyond their immediate subject, and often gave arbitrary names to the parts which they detected. Thus the dissector of the horse, whose attention was more especially called to the leg as the most common seat of disease in that animal, specified its 'cannon-bone,' its 'great' and 'small' pastern-bones, its 'coffin-bone,' and its 'nut-bone' or 'coronet': some cranial bones were also named agreeably with their shape, as the 'os quadratum,' for example. The ornithotomist described, in the same irrelative manner, the 'ossa homoidea,' 'ossa communicantia' or 'interarticularia,' the 'columella' and 'os furcatorium.' Petit* had his 'os grele' and 'os en massue;' Herissant† his 'os carré'; which, however, is by no means the same bone with the 'os carré' or 'os quadratum' of the hippotomist. The investigator of reptilian osteology described 'hatchet-bones' and chevron-bones, an 'os annulare' or 'os en ceinture,' and an 'os transversum': he likewise defined a 'columella'; but this was a bone quite distinct from that so called in the bird. The ichthyotomist had also an 'os transversum,' which again was distinct from that in reptiles, and he demonstrated his 'os discoideum,' 'os cœnosteon,' 'os mystaceum,' 'ossa symplectica prima,' 'secunda,' 'tertia,' 'suprema,' 'postrema,' &c. Similar examples of arbitrary names might easily be multiplied; many distinct ones signifying the same part in different animals, whilst essentially distinct parts often received the same name from different anatomical authors, occupied exclusively by particular species. Each, at the beginning, viewed his subject independently; and finding, therefore, new organs, created a new nomenclature for them; just as the anthropotomist had done, of necessity, when, with a view to the cure or relief of disease and injury, he entered upon the vast domain of anatomical science by the structure of Man, or of the mammals most resembling man.

* Observations Anatomiques sur les mouvemens du bec des Oiseaux, Mémoires de l'Acad. des Sciences, 1748, p. 345.

† Mém. de l'Acad. des Sciences, 1774, p. 497.

It may well be conceived with what a formidable load of names the memory must have been burthened, if any could have been found equal to it, had the anatomy of animals continued and made progress under its primitive condition of an assemblage of arbitrarily described and uncompared facts.

Happily the natural tendency of the human mind to sort and generalize its ideas could not long permit such a state of the science, if science it could be called, to remain. A large and valuable portion of the labours of the comparative anatomists who have honoured the present century, has been devoted to the determination of those bones in the lower animals which correspond with bones in the human skeleton; the results being usually expressed by applying to the parts so determined the same names, as far as the nomenclature of anthropotomy allowed. Few, however, of the parts of the human body have received single substantive names; they are for the most part indicated by shorter or longer descriptive phrases, like the species and parts of plants before Linnæus reformed botanical nomenclature.

The temptation to devise a systematic Nomenclature of Anatomy, generally applicable to all animals, increases with the advance of the science, and from the analogy of what has taken place in other sciences it may one day be yielded to and exercise the ingenuity of some ardent reformer. But the same analogy, especially that afforded by chemical science since the time of Lavoisier, would rather lead the true friend of anatomy to deprecate the attempt to impose an entirely new nomenclature of parts, however closely expressive of the nature and results of the science at the period when it might be devised. For there is no stability in such descriptive or enunciative nomenclature; it changes, and must change with the progress of the science, and thus becomes a heavy tax upon such progress.

If the arbitrary term 'calomel,' which, like 'house' and 'dog,' signifies the thing in its totality, without forcing any particular quality of its subject prominently upon the mind, be preferable, on that account as well as its brevity, to the descriptive phrases 'submuriate of mercury,' 'chloride of mercury,' or 'proto-chloride of mercury,' in enunciating propositions respecting the substance to which it is applied; and if it possesses the additional advantage of fixity, of a steady meaning not liable to be affected, like a descriptive name or phrase, by every additional knowledge of the properties of the substance; the anatomist, zealous for the best interests of his science, will feel strongly the desirableness of retaining and securing for the subjects of his propositions similar single, arbitrary terms, especially if they are also capable of being inflected and used as noun adjectives.

The practice of anatomists of the soundest judgement has usually been, to transfer the anthropotomical term or phrase to the answerable part when detected in other animals. The objection that the original descriptive or otherwise allusive meaning of the term seldom applies to the part with equal force in other animals, and sometimes not at all, is one of really little moment; for the term borrowed from anthropotomy is soon understood in an arbitrary sense, and without regard to its applicability to the modified form which the namesake of the human bone commonly assumes to suit the ends required in the lower species. No anatomist, for example, troubles himself with the question of the amount of resemblance to a crow's or other bird's beak in the 'coracoid' bone of a reptile, or with the want of likeness of the kangaroo's 'coccyx' to the beak of a cuckoo; or of the whale's 'vomer' to a ploughshare; or ever associates the idea of the original mystic allusion in the anatomical term 'sacrum' with his description of that bone in the megatherium or other monster. Common sense gratefully accepts such names when they become as arbitrary as cat or calomel, and when such concretes or adjectives as 'coccygeal,' 'vomerine' and 'sacral' can be employed to teach the properties or accidents of their subjects.

To substitute names for phrases is not only allowable, but I believe it to be indispensable to the right progress of anatomy; but such names must be arbitrary, or, at least, should have no other signification than the homological one, if anatomy, as the science of the structure of all animals, is to enjoy the inestimable benefit of a steady and universal nomenclature. I am far from being insensible to the advantages which other sciences have derived from revolutions in their technical language; but experience has also demonstrated attendant evils; and these, it is to be feared, would preponderate in the case of anatomy, on account of the peculiar character of its origin, and the fact of its cultivators being for the most part introduced to the science through the portal of anthropotomy. So long, likewise, as due deference continues to be paid to the deep and vital importance of the practical applications of the parent science in medicine and surgery, it will be in vain for any man to expect that his sole authority would suffice for the general reception of an entirely new nomenclature, however philosophically devised or clearly enunciative of the highest and most comprehensive truths of the science at the time of its formation.

After maturely considering this subject in its various relations, I have arrived at the conviction that the best interests of anatomical science will be consulted by basing the nomenclature applicable to the vertebrate subkingdom upon the terms and phrases in which the great anthropotomists of the 16th, 17th and 18th centuries have communicated to us the fruits of their immortal labours. For it is only on this firm foundation that we may hope to avoid that ceaseless change of terms which follows the device of a systematic nomenclature significant of a given progress and result of scientific research. But the names of the parts of the vertebrate animals so based on or deduced from the language of anthropotomy must divest themselves of their original descriptive signification, and must stand simply and arbitrarily as the signs of such parts, or at least with the sole additional meaning of indicating the relation of the part in the lower animal to its namesake or homologue in Man. It is an old maxim accepted by the best logicians, that no name is so good as that which signifies the total idea or whole subject, without calling prominently to mind any one particular quality, which is thereby apt to be deemed, undeservedly, more essential than the rest.

The chief improvement which the language of anatomy, based upon that of anthropotomy, must receive in order to do its requisite duty, is the substitution of 'names' for 'phrases' and 'definitions'; and this is less a change of nomenclature than the giving to anatomy what it did not before possess, but which is absolutely requisite to express briefly and clearly, and without periphrasis, propositions respecting the parts of animal bodies. Such names should be derived from a universal or dead language, and when anglicized, or translated into other modern equivalents, ought to be capable of being inflected adjectively.

A few examples will suffice to show how greatly the advantage of such names preponderates over the trouble of substituting them in the memory for the definitions which previously signified the ideas.

In the classical Anthropotomy of Soemmerring, a well-defined part of the skull, which is a distinct bone in the human embryo, and permanently so in all cold-blooded Vertebrata, is called "pars occipitalis stricte sic dicta partis occipitalis ossis spheno-occipitalis*." Monro, in his justly-esteemed treatise 'On the Human Bones†,' defines the same bone as "all the part of the (occipital) bone above the great foramen." In the 'Elements of Anatomy,' by Dr. Quain‡, a work of repute for its clearness and minuteness of detail, the

* De Corporis Humani Fabrica, 1794, t. i. p. 162. † Kirby's edition, 8vo, 1820, p. 76.
‡ Elements of Descriptive and Practical Anatomy, 8vo, 1828, p. 50.

part in question is neither named nor described. The term *supra-occipitale*, Lat. (*supra-occipital*, Eng., *sur-occipital*, Fr.), is obviously a gain to anatomical science in all propositions respecting this part in the vertebrate series.

Certain parts of a vertebra, distinct bones at an early period in man, and throughout life in most reptiles, are defined by Soemmerring as 'radices arcûs posterioris vertebræ,' or 'arcus posterior vertebræ' collectively *. Monro describes the same parts separately, as "a broad oblique bony plate extended backwards," and together, as "a bony arch produced backwards": he names, defines and minutely describes the processes, &c. of these bony plates, which in the series of Vertebrata are soon found to be non-essential characters; but for the plates themselves, which are the most constant and essential constituents of a vertebra, he has no name. Dr. Quain defines the same parts as "two plates of bone, the lamellæ or arches, which complete the central foramen †." They are sometimes more briefly but vaguely spoken of in English works of Comparative Anatomy as "the vertebral lamellæ" or "vertebral laminæ," or "perivertebral elements." The term '*neurapophysis*,' Lat. and Eng. ('*neurapophyse*,' Fr.), applicable to each element individually, under which all its properties may be predicated of by the adjective 'neurapophysial,' without periphrasis, seems by its adoption in the classical works of MM. Agassiz and Stannius, to be as acceptable as the term 'sur-occipital' substituted by Cuvier for the definitions in anthropotomy above cited.

Similar instances of the absence of determinate names, capable of inflection, for parts of the human frame, will be seen in the last column of TABLE I., and others will occur to the anatomist, even in regard to most important parts, as the primary natural divisions of the neural axis, for example, to the great hindrance of brief, clear and intelligible descriptions. So long as the phrases 'marrow of the spine,' 'chord of the spine,' continue to usurp the place of a proper name, all propositions concerning their subject must continue to be periphrastic, and often also dubious. Thus if the pathologist, speaking of diseases of the spinal marrow, desires to abbreviate his proposition by speaking of 'spinal disease,' he is liable to be misunderstood as referring to disease of the spinal or vertebral column. The vague, but often-used phrase 'chorda dorsalis' for the embryonic fibro-gelatinous basis of the spine, adds another source of confusion likely to arise from the use of the term 'spinal chord,' as applied to that most important part of the neural axis which I have proposed to call 'Myelon ‡,' a term which, if adopted, would be attended by this advantage, that no ambiguity could arise in speaking of 'myelonal functions,' 'myelonal affections,' or other properties of this part of the central axis of the nervous system.

Anthropotomy, in respect to its nomenclature, or rather the want of one, is, as I have already remarked, not unlike what botany was before the time of Linnæus, and we may anticipate the happiest effects from a judiciously reformed technical language in the advancement of the true and philosophic knowledge of the human structure, from the rapid progress of botany when the opposition raised by sloth or envy to the Linnæan reforms was overcome. For a good general anatomical nomenclature, based and regulated upon the principles above defined, must reflect its benefits upon anthropotomy. I dare not flatter myself that the names adopted or proposed for the Osseous System of the Vertebrata in my 'Hunterian Lectures' and in the first column of Table I. will meet at once with acceptance, but the attempt to establish such a nomenclature will be felt to have been an indispensable step in undertaking a general survey of the homological relations of the vertebrate skeleton.

* De Corporis Humani Fabrica, 1794, t. i. pp. 235, 236.

† Elements of Descriptive and Practical Anatomy, 8vo, 1828, p. 121.

‡ Hunterian Lectures, vol. ii. 'Vertebrata,' part i. p. 172.

In proposing a definite name for each distinct bone, declaratory of its special homology throughout the vertebrate kingdom, I have sought earnestly to reduce the amount of reform to the minimum allowed by the exigences of the case. Agreeably with Aphorism III. of the 'Philosophy of the Inductive Sciences' (p. lxvii.), the nomenclature of anthropotomy forms the basis, and all the names given to parts by one or other of the great French anatomists have been accepted, with the modifications of a Latin or an English termination, wherever such names had not been applied, as is the case with some proposed by Geoffroy St. Hilaire, to two different parts. In substituting names for phrases, I have endeavoured, conformably with another of Dr. Whewell's canons (Aph. XVII. *op. cit.* p. cxvii.), to approximate the sound of the name as nearly as possible to those of the leading terms of the definition or phrase, as e. g. *alisphenoid* for 'ala media, &c. sphenoidalis' and for 'grande aile du sphénoïde'; *orbitosphenoid* for 'ala superior seu orbitalis, &c. sphenoidalis,' and for 'aile orbitaire du sphénoïde*.'

The corresponding parts in different animals being thus made namesakes, are called technically 'homologues.' The term is used by logicians as synonymous with 'homonyms,' and by geometricians as signifying 'the sides of similar figures which are opposite to equal and corresponding angles,' or to parts having the same proportions†: it appears to have been first applied in anatomy by the philosophical cultivators of that science in Germany. Geoffroy St. Hilaire says, "Les organes des sens sont *homologues*, comme s'exprimerait la philosophie Allemande; c'est-à-dire qu'ils sont analogues dans leur mode de développement, s'il existe véritablement en eux un même principe de formation, une tendance uniforme à se répéter, à se reproduire de la même façon‡." The French anatomist, however, seems not rightly to define the sense in which the German philosophers have used the term: there is a looseness in the expression 'analogous in their mode of development,' which may mean either identical or similar, and also different kinds of similarity. Parts are homologous in the sense in which the term is used in this Report, which are not always similarly developed: thus the 'pars occipitalis stricte sic dicta,' &c. of Soemmerring is the special homologue of the supraoccipital bone of the cod, although it is developed out of pre-existing cartilage in the fish and out of aponeurotic membrane in the human subject. I also regard the supraoccipital as the serial homologue of the parietal and the midfrontal, although these are developed out of the epicranial membrane in the fish, and not out of pre-existing cartilage, like the supraoccipital. The femur of the cow is not the less homologous with the femur of the crocodile, because in the one it is developed from four separate ossific centres, and the other from only one such centre. In like manner the compound mandibular ramus of the fish is the homologue of the simple mandibular ramus of the mammal, as the compound tympanic pedicle of the fish is homologous with the simple tympanic pedicle of the bird, the differences expressed by the terms 'simple' and 'compound' depending entirely on a difference of development.

Without knowing the precise sense in which Geoffroy St. Hilaire under-

* The happy facility of combination which the German language enjoys has long enabled the very eminent anatomists of that intellectual part of Europe to condense the definitions of anthropotomy into single words; but these cannot become cosmopolitan; such terms as 'Hinterhauptbeinkörper,' 'Schläfbeinschüppen,' and 'Zwischenkiemendeckelstück,' are likely to be restricted to the anatomists of the country where the vocal powers have been trained from infancy to their utterance.

† This is the sense in which the term is defined in the French Dictionary and in our Johnson's Dictionary.

‡ Annales des Sciences Naturelles, tom. vi. 1825, p. 341.

stood 'analogous development,' one cannot determine how much or how little it is applicable to the determination of homologies or to the definition of homologous parts. Dr. Reichert seems to have been unduly influenced by the idea of 'analogy or similarity of development in the determination of homologous parts' when he rejected the parietal and frontal bones from the system of the endo-skeleton, because they were not developed from a pre-existing cartilaginous basis*, or, because they could be easily detached from subjacent persistent cartilage in certain fishes; the essential distinction between these and the supra-occipital in regard to development being, that whereas the cartilaginous stage intervened in the latter between the membranous and the osseous stages, in the other, usually more expanded, cranial spines, the osseous change appears to be immediately superinduced upon the primitive aponeurotic histological condition.

M. Agassiz seems, in like manner, to give undue importance to similarity of development in the determination of homologies, where he repudiates the general homology of the basi-sphenoid with the vertebral centrum, and consequently its serial homology with the basi-occipital, because the pointed end of the chorda dorsalis has not been traced further forwards along the basis of the cranium in the embryo osseous fish than the basi-occipital†. But the development of the centrum of every vertebra begins, not in the gelatinous chord, but in its aponeurotic capsule, and it is in the expanded aponeurosis directly continued from the 'chorda' along the 'basis cranii' that the thin stratum of cartilage-cells is formed from which the ossification of the basi-sphenoid, presphenoid and vomer proceeds.

There exists doubtless a close general resemblance in the mode of development of homologous parts; but this is subject to modification, like the forms, proportions, functions and very substance of such parts, without their essential homological relationships being thereby obliterated. These relationships are mainly, if not wholly, determined by the relative position and connection of the parts, and may exist independently of form, proportion, substance, function and similarity of development. But the connections must be sought for at every period of development, and the changes of relative position, if any, during growth, must be compared with the connections which the part presents in the classes where vegetative repetition is greatest and adaptive modification least.

Relations of homology are often not only confounded with those of analogy, but in some recent and highly estimable works on comparative anatomy the terms 'analogy' and 'analogue' continue to be used to express the ideas of homology and homologue, or are so used as to leave in doubt the meaning of the author. Thus when we read in the latest edition of the 'Leçons d'Anatomie Comparée' of Cuvier, "Les branchies sont les poumons des animaux absolument aquatiques," t. vii. p. 164; and with regard to the cartilaginous or osseous supports of the gills, "elles sont, à notre avis, aux branchies des poissons, ce que les cerceaux cartilagineux ou osseux des voies aériennes sont aux poumons des trois classes supérieures," *Ibid.* p. 177, we are left in doubt whether it is meant that the gills and their mechanical supports merely perform the same function in fishes which the lungs and windpipe do in mammals, or whether they are not also actually the same parts differently modified in relation to the different respiratory media in the two classes of animals. The deeper-thinking Geoffroy leaves no doubt as to his meaning where he argues

* Vergleichende Entwickelungsgeschichte des Kopfes der nackten Reptilien, 4to, 1838, pp. 212, 218.

† Recherches sur les Poissons Fossiles, 4to, 1843, i. p. 127.

in the 'Philosophie Anatomique' (8vo, 1818, 41ème mémoire, p. 205), that the branchial arches of fishes are the modified tracheal rings of the air-breathing vertebrates: we perceive at once that he is enunciating a relation of homology.

I have elsewhere* discussed the relations, both homological and analogical, of the respiratory organs of the air-breathing and water-breathing vertebrate animals, and have here adverted to them merely to illustrate the essential distinction of those relations. In the 'Glossary' appended to the first volume of my 'Hunterian Lectures,' the terms in question are defined as follows:—

"ANALOGUE."—A part or organ in one animal which has the same function as another part or organ in a different animal.

"HOMOLOGUE."—The same organ in different animals under every variety of form and function†."

The little 'Draco volans' offers a good illustration of both relations. Its fore-limbs being composed of essentially the same parts as the wings of a bird are homologous with them; but the parachute being composed of different parts, yet performing the same function as the wings of a bird, is analogous to them. Homologous parts are always, indeed, analogous parts in one sense, inasmuch as, being repetitions of the same parts of the body, they bear in that respect the same relation to different animals. But homologous parts may be, and often are, also analogous parts in a fuller sense, viz. as performing the same functions: thus the fin or pectoral limb of a Porpoise is homologous with that of a Fish, inasmuch as it is composed of the same or answerable parts: and they are the analogues of each other, inasmuch as they have the same relation of subserviency to swimming. So, likewise, the pectoral fin of the flying-fish is analogous to the wing of the Bird, but, unlike the wing of the Dragon, it is also homologous with it.

Relations of homology are of three kinds: the first is that above defined, viz. the correspondency of a part or organ, determined by its relative position and connections, with a part or organ in a different animal; the determination of which homology indicates that such animals are constructed on a common type: when, for example, the correspondence of the basilar process of the human occipital bone with the distinct bone called 'basi-occipital' in a fish or crocodile is shown, the *special homology* of that process is determined.

A higher relation of homology is that in which a part or series of parts stands to the fundamental or general type, and its enunciation involves and implies a knowledge of the type on which a natural group of animals, the vertebrate for example, is constructed. Thus when the basilar process of the human occipital bone is determined to be the 'centrum' or 'body of the last cranial vertebra,' its *general homology* is enunciated.

If it be admitted that the general type of the vertebrate endo-skeleton is rightly represented by the idea of a series of essentially similar segments succeeding each other longitudinally from one end of the body to the other, such segments being for the most part composed of pieces similar in number and arrangement, and though sometimes extremely modified for special functions, yet never so as to wholly mask their typical character,—then any given part of one segment may be repeated in the rest of the series, just as one bone may be reproduced in the skeletons of different species, and this kind of repetition or representative relation in the segments of the same skeleton I call 'serial homology.' As, however, the parts can be namesakes only in a general sense, as centrums, neurapophyses, ribs, &c.; and since

* Lectures on Vertebrata, 1846, p. 279.

† Lectures on Invertebrate Animals, 8vo, 1843. Glossary, pp. 374, 379. My ingenious and learned friend Mr. Hugh Strickland has made a strong and able appeal to the good sense of comparative anatomists in favour of the restriction of these terms to the senses which they are here defined.—Phil. Mag. 1846, pp. 358, 362.

they must be distinguished by different special names according to their particular modifications in the same skeleton, as *e. g.* mandible, coracoid, ilium, &c., I call such serially related or repeated parts 'homotypes.' The basi-occipital is the homotype of the basi-sphenoid; or in other words, when the basi-occipital is said to repeat in its vertebra or natural segment of the skeleton the basi-sphenoid or body of the parietal vertebra, or the bodies of the atlas and succeeding vertebræ, its *serial homology* is indicated. The study of this kind of homologies was commenced by Vicq d'Azyr, in his ingenious memoir 'On the Parallelism of the Fore and Hind Limbs.' If we except the complex and extremely diversified and modified parts of the radiated appendages of the vertebral segments, to which Vicq d'Azyr restricted his comparisons, the serial homologies of the skeleton are necessarily demonstrated when the general and special homologies have been determined.

In the present section of this Report I propose to consider some of those examples of special homology which are least satisfactorily determined and respecting which different opinions still sway different anatomists. Such instances are fortunately few, thanks to the persevering and successful labours of the great comparative anatomists of the last half-century: pre-eminent amongst whom will ever stand the name of CUVIER, in whose classical works, 'Ossemens Fossiles,' 'Histoire des Poissons,' 'Leçons d'Anatomie Comparée' (posthumous edition), and 'Règne Animal,' 1828, will be found the richest illustrations of the special homological relations of the bones in the four classes of vertebrate animals.

Second only to CUVIER must be named GEOFFROY ST. HILAIRE, whose memoir on the Bones of the Skull in Birds as compared with those in Mammals, in the 'Annales du Muséum, t. x. (1807), forms an early and brilliant example of the quest of special homologies, which could not fail, with other and similar investigations of the same ingenious author, to impart a stimulus to that philosophical department of anatomical inquiry*. In regard to the osteology of the crocodile, we find Cuvier and Geoffroy engaged in a long parallel series of rival researches, the results of which have had the happiest effects in determining some of the most difficult questions of special homology.

Nor was the co-operation of zealous cultivators of comparative anatomy wanting in the eminent schools and universities of Germany. GOETHE, indeed, had taken the lead in inquiries of this nature in his determination, in 1787, of the special homology of that anterior part of the human upper maxillary bone which is separated by a more or less extensive suture from the rest of the bone in the fœtus; and the philosophical principles propounded in the great poet's famous anatomical essays called forth the valuable labours of the kindred spirits, OKEN, BOJANUS, MECKEL, CARUS, and other eminent cultivators of anatomical philosophy in Germany.

It is not requisite for the purpose I have in view, to trace step by step the progress of the special homological department of anatomy. Its present state, as regards the skull of the Vertebrata, will be best exposed by the subjoined tabular view of the fruits of the latest inquiries.

TABLE I. (See end of the Report.)

This table gives at one view the general results of the researches into the conformity of structure of the skull throughout the vertebrate series,

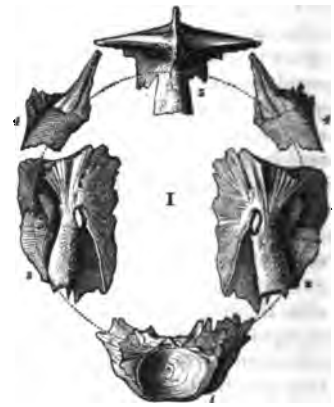
* Oken's famous "Programm, Über die Bedeutung der Schädelknochen" was published in the same year (1807) as Geoffroy's Memoir on the Bird's skull; but it is devoted less to the determination of 'special' than of 'general homologies': it has, in fact, a much higher aim than the contemporary publication of the French anatomist, in which we seek in vain for any glimpse of "[illegible]lations of the bones of the skull, the discovery of which has conferred imr[illegible]me of OKEN.

by the two great French anatomists who have most advanced this part of osteological science; by the authors of two classical German works on Comparative Anatomy; and by their countryman Dr. Hallmann, who has detailed in an elaborate treatise his especial investigations of some of the most difficult parts of this difficult inquiry. I have added the synonyms of the bones of the head of fishes from the great work of the celebrated Swiss naturalist, who has, so happily for ichthyology, devoted himself to the advancement of that interesting branch of Natural History; and also, the anthropotomical terms for the corresponding parts in the human skeleton. These, after much comparison and deliberation, I have chosen from the justly-celebrated work of SOEMMERRING, the high reputation of which has been sanctioned by the new edition to which some of the most eminent of the German professors of anthropotomy and physiology have recently devoted their combined labours. The English teacher of these sciences will find some of the descriptive designations of the parts by Soemmerring not agreeing with those which he may be in the habit of using, and which are current in the later Manuals of Anthropotomy published in this country: the 'ossa lateralia lingualia' are more commonly called, with us, the 'cornua majora ossis hyoidei'; the 'os spheno-occipitale' is generally described as two distinct bones, the 'os occipitis' and 'os sphenoide'; the 'pars occipitalis stricte sic dicta,' &c. is sometimes called 'squama occipitalis,' or occipital plate; and other synonyms might easily be multiplied from the osteological treatises of Monro and later authors of repute. The fact of such a conflicting and unsettled synonymy still pervading the monographs relating to the human structure, should stimulate the well-wisher to the right progress of anatomy to lend an earnest aid to the establishment of a fixed and determinate nomenclature. A little present labour and the example of adoption, where the reasonableness and necessity of the reform are plain and undeniable, will much accelerate the future progress of anatomical science; and I would respectfully appeal to the Professors and Demonstrators of Human Anatomy for an unbiassed consideration of the advantages of the terms proposed in the first column in Table I. It is designed to express the results of a long series of investigations into the special homologies of the bones of the head, in simple and definite terms, capable of every requisite inflection to express the properties of the parts, and applicable to the same bones from the highest to the lowest of the vertebrate series.

The degree and extent of the diversity of my determinations from those of other anatomists are shown in the succeeding columns, headed by their names; and I proceed now to give the reasons which have compelled me, in such instances, to dissent from the high authority of Cuvier, Geoffroy, Meckel, Hallmann and Agassiz: these reasons will exonerate me, I trust, from the reproach of underrating their justly-esteemed opinions, which have been abandoned only where nature seemed clearly to refuse her sanction to them. The instances of such dissent are much fewer than they appear to be at first sight. In most cases, where the names differ, the determinations are the same. For 'basilaire,' which Cuvier exclusively applies to the 'pars basilaris' of the occiput, and which Geoffroy as exclusively applies (in birds) to the 'pars basilaris' of the sphenoid, I have substituted the term 'basioccipital' (*basi-occipitale*, Lat.); a term which, as it is more descriptive of the bone in question (1 figs. 1 to 25), will, perhaps, be the more acceptable to those who prefer a determinate to a variable nomenclature, since Cuvier himself has almost as frequently applied to that bone the term 'occipital inférieur' as the term 'basilaire.' For the descriptive phrase 'occipital latéral,' the term 'exoccipital' (*exoccipitale*, Lat.), proposed by Geoffroy, is preferable for

the bones 2,2, figs. 1 to 25; especially since the paroccipital is the most 'lateral' of the elements of the occipital bone, in the definite sense in which the term 'lateral' is used in the precise and excellent anatomical nomenclature of Dr. Barclay. For the numerous synonyms borne by the element 3 of the occipital segment of the skull, the term 'supraoccipital' (*supra-occipitale*, Lat.) seemed to best agree with the truest descriptive phrase of the part, viz. 'occipital supérieur.' The interparietal is no constant cranial element, nor is it a dismemberment of one and the same bone of the skull. It is at best only the largest and most common of the accidentally intercalated 'ossa wormiana.' Sometimes, for example, in the *Cebus* monkey, it is a dismemberment of the backwardly-produced frontal bone: more frequently it is the detached upper angle of the supraoccipital. But by this term 'supraoccipital,' I signify the totality of the bone 3 (in figs. 1, 5, 18, 22, 23, 24, 25), confining the term interparietal to its superior and anterior apex when detached, or to the superior and posterior apex of the frontal, when it is in like manner detached and wedged between the parietal bones. The inapplicability of the term 'interparietal' to the whole of the supraoccipital is strongly manifested in those fishes, *e.g.* the carp and tench, in which the supraoccipital is withdrawn from between the parietals to the back part of the skull, leaving those bones to come into contact and unite by the normal sagittal suture on the mesial line of the vertex. Geoffroy's error is of the same kind, and scarcely greater than Cuvier's, where he applies the term 'interparietal' to the whole of the parietal bones in Birds*. The supraoccipital thus defined can never be mistaken for the 'sur-occipital' of Geoffroy, who by this term signifies the elements called 'occipitaux externes' by Cuvier. At the same time the term 'sur-occipital' is too near in sound to 'supraoccipital,' and too significant of the highest part of the occipital segment to be retained for elements, which, like the 'paroccipitals' (fig. 1, 4, 4), are usually inferior in position to the supraoccipital. Geoffroy, moreover, is not consistent in his application of the term 'sur-occipital.' In his memoir on the skull of the crocodile in the 'Annales des Sciences' for 1824, he applies that term to a part of the bone†, the whole of which he calls 'exoccipital' in his later memoir, on the skull of the crocodile, of 1838‡; whilst in the memoir illustrated by the skull of the Sea-perch (*Serranus gigas*) in the 'Annales des Sciences' for 1825, the term 'suroccipital' is applied to the whole of the bones described as 'occipitaux externes' by Cuvier. I trust, therefore, to have shown the necessity for the definite name of 'paroccipital' (*paroccipitale*, Lat.) which is here proposed for the elements, 4, of the occipital segment of the cranium (figs. 1 and 5). The name has reference to the general homology of the bones in question, as 'parapophyses' or transverse processes of the occipital vertebra. And if the purists who are distressed by such harmless hybrids as 'mineralogy,' 'terminology' and 'mam-

Fig. 1.



Disarticulated epencephalic or neur-occipital arch, viewed from behind: Cod (*Morrhua vulgaris*).

* Annales du Muséum, x. p. 363, pl. 27.

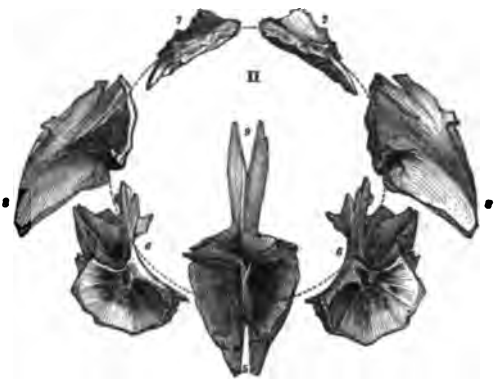
† Pl. 16. fig. 5 *z*+R. "Plur-occipital formé du sur-occipital et de l'ex-occipital."

‡ Mémoires de l'[illegible]des Sciences, t. xii. Atlas, p. 43.

malogy,' should protest against the combination of the Greek prefix to the Latin noun, I can only plead that servility to a particular source of the fluctuating sounds of vocal language is a matter of taste; and that it seems no unreasonable privilege to use such elements as the servants of thought; and, in the interests of science, to combine them, even though they come from different countries, where the required duty is best and most expeditiously performed by such association.

For the same motive that suggested the term basi-occipital, viz. because the anthropotomist has been long accustomed to hear that and the corresponding element of the sphenoid bone described as 'basilar processes,' I propose to substitute the term 'basisphenoid' (*basisphenoideum*, Lat.) for the three different descriptive phrases applied to the part (s, figs. 2, 5, 19, &c.) by Cuvier, for the two additional synonyms of Geoffroy, and for the 'sphenoideum basilare' of Hallmann. 'Alisphenoid' (*alisphenoideum*, Lat., e, e, figs. 2. 5, 19, &c.) seemed to retain most of the old anthropotomical term of 'alæ majores,' or wings 'par excellence' of the os sphenoideum; as 'orbitosphenoid' (*orbito-sphenoideum*, 10, 10, figs. 3 and 20) best recalls or expresses the idea conveyed by the descriptive phrase 'alæ orbitales,' or 'ailes orbitaires,' often applied to the homologous bones, regarded as processes of the sphenoid in human anatomy. Here, however, in reference to the alisphenoid, we find the first marked discrepancy in the conclusions of the anatomists who have particularly studied its special homologies. The bone which appears as the 'grande aile du sphénoïde' to Cuvier and Agassiz in fishes, is the 'petrosum' to Hallmann and Wagner; it is also 'rocher' (petrosal) to Cuvier himself in reptiles, and is again 'grande aile du sphénoïde' in birds and mammals. The reasons which have led me to the conclusion that the bones so denominated, as well as the 'ptéreal' and 'prérupeal' of Geoffroy, are homologously one and the same, are so intimately linked with the consideration of the true petrosal and of other elements of the anthropotomist's 'temporal bone,' that I reserve the discussion of these questions until I have completed the apology for the names proposed in the first column of Table I.

Fig. 2.

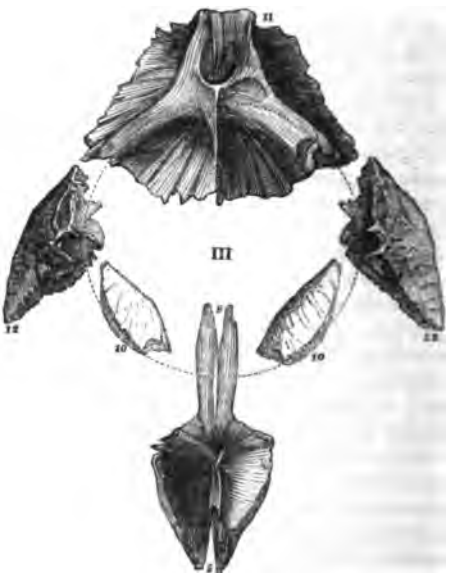


Disarticulated mesencephalic or neuro-parietal arch, viewed from behind: Cod-fish.

The 'parietal' (*parietale*, Lat., 7, 7, figs. 2, 5, 19, &c.) and 'mastoid' (*mastoideum*, Lat., s, s, figs. 2, 5, 19, &c.) are amongst the few bones that have had the good fortune to receive, originally, definite names, applicable to them throughout the vertebrate series; although the mastoid, being like the par-occipital, essentially a parapophysis, loses its individuality sooner than do other bones of its segment, and becomes, therefore, a 'processus mastoideus ossis temporis,' in the language of anthropotomy. The homology of the 'parietal' has fortunately been, with a single exception, universally recognised throughout the vertebrate subkingdom; the exception being furnished by the eccentric homologist Geoffroy, who is, as usual, inconsistent with himself, even on this plainest and least mistakeable point.

The term 'presphenoid' (*presphenoideum*, Lat. 9, figs. 3, 5, 20, 24, 25, &c.) is proposed for the 'sphénoïde antérieur,' on the principle of substituting, as the better instrument of thought, a definite name for a descriptive phrase. For the same reason 'postfrontal' (*postfrontale*, Lat., 12, 12, figs. 3, 5, 20, &c.) is substituted for Cuvier's 'frontal postérieur' and its synonyms. The 'frontal' (*frontale*, Lat. 11, figs. 3, 5, 20, &c.) and 'vomer' (*vomer*, Lat., 13, figs. 4, 5, 20, 25), are among the few bones which have had their special homologies recognised unanimously throughout the vertebrate subkingdom; in the one case even without departure from the original anthropotomical name, and in the other, with but a single deviation from the established nomenclature. But when Geoffroy was induced to reject the term 'vomer' as being applicable only to the peculiar form of the bone in a small proportion of the vertebrata, he appears not to have considered that the old term, in its wider application, would be used without reference to its primary allusion to the ploughshare, and that becoming, as it has, a purely arbitrary term, it is superior and preferable to any partially descriptive one. 'Rhinosphénal,' it is true, recalls the idea of the vomer forming the continuation in the nasal segment of the skull of the basi- and pre-sphenoidal series of bones in other segments; but 'vomer,' used arbitrarily, summons equally every idea derived to form the complex whole from the general study of the bone throughout the vertebrate series.

Fig. 3.



Disarticulated prosencephalic or neuro-frontal arch, viewed from behind: Cod-fish.

'Prefrontal' (*prefrontale*, Lat., 14, 14, figs. 4, 5, 21, &c.) claims the same preference over anterior frontal, and its foreign equivalents, as does postfrontal over its synonymous phrases. There is also another reason for proposing the term; viz. because it is applied to bones in the vertebrate series generally, according to conclusions as to their homological relations, which differ from those to which Cuvier and Geoffroy had arrived. The discussion of the discordant denominations at present applied to this important element of the skull will be fully carried out in the sequel. 'Nasal' (*nasale*, 15, figs. 4, 5, 21, &c.) is another of the few instances in which it is possible to retain and generally apply an old and received anthropotomical term. No one, it is presumed, will con-

Fig. 4.

Disarticulated rhinencephalic, or neuro-nasal arch, viewed from behind: Cod-fish.

tend for the perpetual expression or insertion of the understood generic word 'bone' or '*os*' in this case any more than in the parietal, frontal, &c., which, from being originally specific adjectives, have been properly and conveniently converted into definite nouns.

In conformity with this mode of acquiring an improved as well as brief and precise expression of anatomical facts, I have substituted for 'pars petrosa' or 'os petrosum' the substantive term 'petrosal' (Lat. *petrosum*, figs. 5, 25, 16). The necessity for some such designation for an essentially and often physically distinct bone in the vertebrate skull has been felt by both Cuvier and Geoffroy, when they respectively proposed the names 'rocher' and 'rupéal' for the element in question. 'Petrosal' has appeared to me to be the best English equivalent of Cuvier's 'rocher'; as containing the most characteristic vocable of the old anthropotomical descriptive phrase 'pars petrosa ossis temporis,' &c. 'Rupéal' unfortunately has no determinate meaning: it is applied by its author with certain prefixes to several distinct bones, which already had their proper names. 'Sclerotal' (*sclerotale*, Lat., figs. 5, 22, 23, 17) for 'ossicula seu laminæ osseæ membranæ sclerotice,' is proposed on the same grounds as exoccipital, postfrontal, &c., viz. the substitution of a name for a phrase. The sclerotals have not been usually included amongst the bones of the head, though they have precisely the same claims to that rank as the petrosals, or other bony capsules of the organs of special sense. Retaining the old anthropotomical term 'ethmoid,' I restrict its application to the very irregular and inconstant developments of bone in the cartilage or membrane which is applied to the anterior outlet of the cranium proper, for the support or defence of the cranial part of the organ of smell. The 'ossa turbinata superiora,' and the 'cellulæ æthmoideæ' are parts of the capsule of that sense, extensively developed in the mammalia, to which the term ethmoid may properly apply; but they must always be distinguished from the modified though constant neurapophyses of the nasal vertebra, called 'prefrontals,' with which the above developments of the olfactory capsule usually coalesce in birds and mammals. 'Turbinal' (*turbinale*, Lat., figs. 5, 25, 19), like petrosal, is a substitute for the phrase 'os turbinatum inferius,' and its synonym 'os spongiosum inferius.'

'Palatine' (*palatinum*, Lat., *ib.* 20) is another of the few fortunate instances of the general recognition of the homologous bone throughout the vertebrate kingdom, with the further advantage of a steady retention of a good old name.

'Maxillary' (*maxilla*, Lat., *ib.* 21) is a similar instance; but Geoffroy, as usual, makes himself singular by adding an uncalled-for synonym. If Soemmerring's term 'mandibula' for the lower jaw were universally adopted and constantly understood to signify the totality of that part of the tympano-mandibular arch throughout the vertebrate series, it would be unnecessary to encumber 'maxilla' with the distinctive epithet 'superior,' which, indeed, expresses a character peculiar only to Man and a few mammalia: in the vertebrate series the 'maxilla' is more commonly anterior than superior to the 'mandibula.'

I have adopted the term 'premaxillary' (*premaxillare*, Lat. *ib.* 22), as used by M. de Blainville and some other distinguished continental osteologists, in preference to 'intermaxillary;' because that term has already been applied (by Schneider) to another bone of the skull (the tympanic in birds), of which it is more accurately descriptive, than it is of a bone which is more commonly before than between the maxillary bones. 'Entopterygoid' (*entopterygoideum*, Lat.) claims preference to the phrases 'ptérygoïde interne' of Cuvier and Agassiz, on the same logical grounds as have already been urged in favour of 'exoccipital,' 'prefrontal,' &c. But I have also another reason for proposing a definite term for the bone 22, fig. 5, which I regard as a peculi-

ichthyic development. Cuvier has applied the term 'ptérygoïde interne' to another part of the diverging appendage of the palato-maxillary arch, which part, I concur with Dr. Köstlin in regarding as homologically distinct from the 'entopterygoid' of fishes. For the part in question, viz. the 'os transverse' of Cuvier in the skull of fishes (24, fig. 5), and its homologue in reptiles, which he calls 'ptérygoïdien interne' (24, fig. 22), I retain the term 'pterygoid' (*pterygoideum*, Lat.), meaning pterygoid proper: and to the bone which Cuvier calls 'transverse' in reptiles (24', fig. 22), I apply the term 'ectopterygoid' (*ectopterygoideum*, Lat.); but this, as the table demonstrates, does not signify Cuvier's 'os transverse' in the skull of fishes. Entopterygoid, pterygoid and ectopterygoid, have, therefore, both the advantages of substantive terms, and of being applied steadily each to a distinct bony element. The 'hérisséal' of Geoffroy, like the 'ptérygoïde interne' of Cuvier, means one thing in a fish and another in a crocodile; Geoffroy has also encumbered the latter bone with a third synonym. 'Malar' (*malare* or *os malæ*, Lat.) is preferable to 'jugal,' because Cuvier applies that name to one bone in a fish, to another in a mammal, and to two essentially distinct though coalesced bones in a bird. Malar is also the name most commonly applied by English anthropotomists to the bone, to the true homologue of which I would restrict its application throughout the vertebrate series.

With regard to the 'squamosal' (*squamosum*, Lat. pars squamosa, &c., figs. 22–25, 27), it may be asked why the term 'temporal' might not have been retained for this bone. I reply, because that term has long been, and is now universally, understood in human anatomy to signify a peculiarly anthropotomical coalesced congeries of bones which includes the 'squamosal' together with the 'petrosal,' the 'tympanic,' the 'mastoid,' and the 'stylohyal.' It seems preferable, therefore, to restrict the signification of the term 'temporal' to the whole (in Man) of which the 'squamosal' is a part. To this part Cuvier has unfortunately applied the term 'temporal' in one class and 'jugal' in another: and he has also transferred the term 'temporal' to a third equally distinct bone in fishes; whilst to increase the confusion, M. Agassiz has shifted the name to a fourth different bone in the skull of fishes. Whatever, therefore, may be the value assigned to the arguments which will be presently set forth, as to the special homologies of the 'pars squamosa ossis temporis,' I have felt compelled to express the conclusion by a definite term, and, in the present instance, have selected that which recalls best the accepted anthropotomical designation of the part, although 'squamosal' must be understood and applied in an arbitrary sense, and not as descriptive of a scale-like form, which, in reference to the bone so called, is rather its exceptional than normal figure in the vertebrate series.

The term 'tympanic' (*tympanicum*, Lat.) appears to have received the most general acceptance as applied to that bone which the early ornithotomists have called 'os quadratum' and 'os intermaxillare,' (fig. 23, 28) and which as a process of the human temporal, sometimes called 'external auditory,' supports the tympanic membrane (fig. 25, 28). 'Caisse' is the French and 'pauke' the German equivalent; but Cuvier more commonly uses the phrase 'os tympanique.' The chief point, in reference to that term, as applied by Cuvier, from which I find myself compelled to dissent from the great and ever-to-be-revered anatomist, relates to the view which he has taken of the large and long pedicle which supports the mandible in fishes, and which, in that class, is subdivided into sometimes two, sometimes three, and commonly into four pieces. I regard this subdivision of the elongated supporting pedicle as explicable chiefly, if not solely, by reference to a final purpose, viz. to combine strength with a certain elastic yielding and power of recovery, in the constant and powerful movements to which it is subject in the transmission of the respi-

ratory currents, and in the prehension and deglutition of the food. Cuvier himself regards in the same light the analogous subdivision of the mandibular or lower half of the arch, and both Conybeare* and Buckland† have well illustrated the final purpose which the subdivision of the lower jaw of the Crocodile into overlapping pieces, subserves. Cuvier has given distinct and convenient names to these several pieces of the mandible, but he views them collectively as answering to the simple mandible of the mammal and the bird. I, in like manner, regard the subdivided pedicle supporting the mandible in fishes as answering to the undivided pedicle supporting the mandible in ophidians, lizards and birds. There is the same necessity or convenience for a distinct name to each distinct part of the tympanic pedicle, or upper part of the tympano-mandibular arch, as for the divisions of the mandible or lower part of that arch. But Cuvier unfortunately persuaded himself that the subdivisions of the tympanic pedicle in fishes represented other bones in higher vertebrates besides the tympanic, and applied to them the names of such bones. I have been compelled, therefore, in dissenting from this view to propose new names for the peculiar ichthyic subdivisions of the tympanic, and in doing so I have been careful to retain the dominant term, and to distinguish the parts by prefixes indicative of their relative position. Time and the judgement of succeeding homologists will determine the accuracy or otherwise of this view; and, should it be ultimately adopted, I feel great confidence that the terms 'epitympanic' (*epitympanicum*, Lat., fig. 5, 22*a*), mesotympanic (*mesotympanicum*, 22*b*), pretympanic (*pretympanicum*, 22*c*) and hypotympanic (*hypotympanicum*, 22*d*), will be preferred to the names proposed by Geoffroy St. Hilaire for the same parts. With regard to the subdivisions of the mandible in cold-blooded vertebrates, I adopt most of those proposed by Cuvier. As, however, 'operculaire' had been applied by the great anatomist to a distinct bone in fishes, it was necessary, in order to avoid its use in a double sense, to substitute a distinct name for the part of the jaw in question, and as it is always applied, like a surgeon's splint or plaster to the inner side of most of the other pieces, that of 'splenial' (*splenium*, Lat., figs. 22, 23, 21) suggested itself to me as the most appropriate name. For an obvious reason I have restored the term 'coronoid' (*coronoideum*, 21′) in place of 'complementary,' for the piece into which the crotaphite muscle is always more or less inserted in the mandible of reptiles. There is no ground for disturbing the appropriate names given by Cuvier to the parts of the diverging appendage of the tympano-mandibular arch in fishes; and the same principle which he has adopted in distinguishing the different opercular bones (fig. 5, 24–27), has guided me in naming the different parts of the bony pedicle which supports them.

I have gladly adopted as many of the well-devised terms which Geoffroy proposed for the elements of the hyoid arch, as his unsteadiness in their application would permit to be retained. They are obviously preferable to the descriptive phrases by which Cuvier designates the homologous parts.

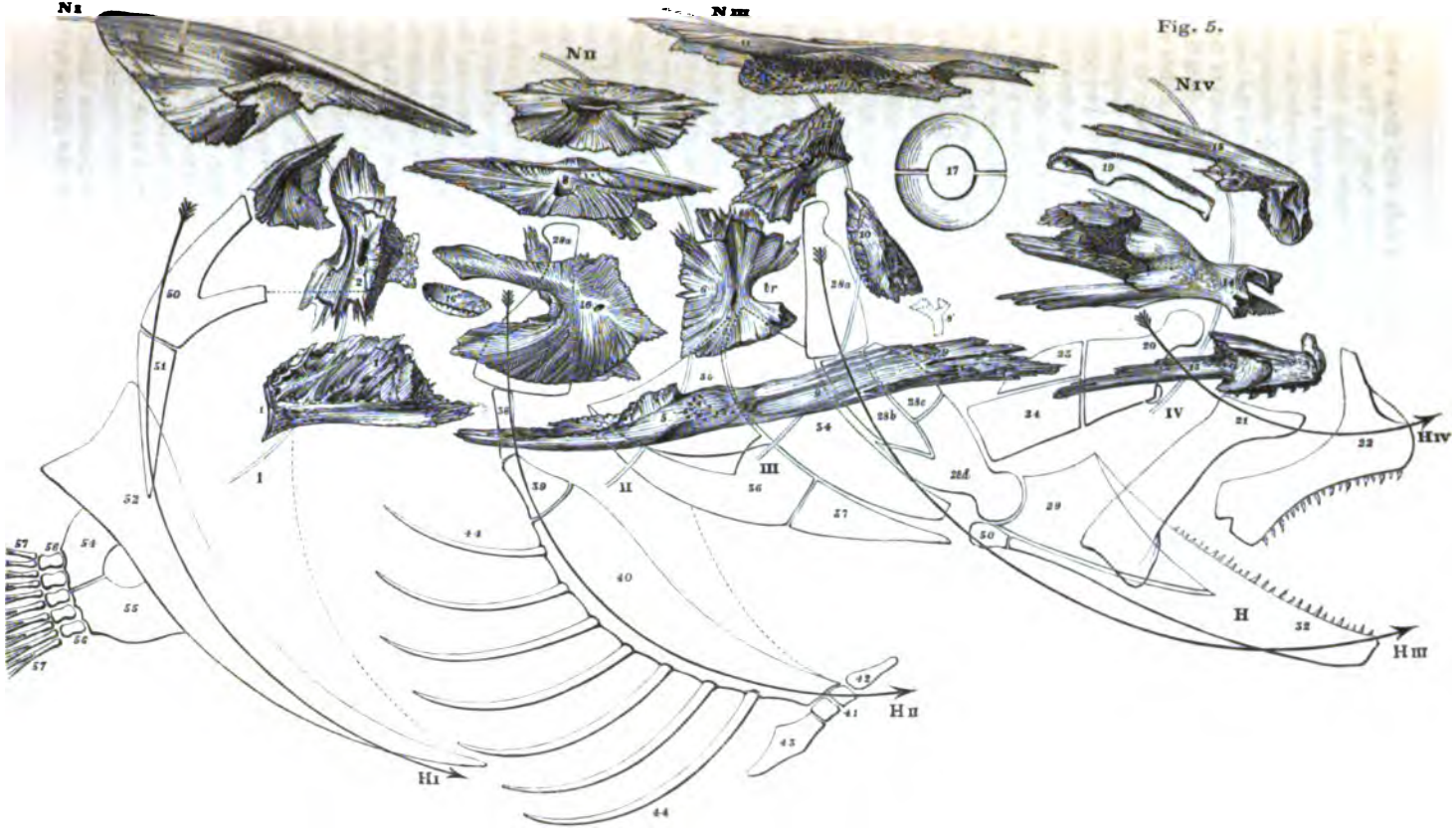
The substantive terms applied to the corresponding divisions of the branchial arches have been modelled on those of the hyoid system; but I have deviated in one instance from the rule which has governed throughout my nomenclature of the bones, in proposing a second name for a modified homologue in the air-breathing animals, of a part of the branchial apparatus in fishes, viz. that part which is retained even in the human hyoid, and which is known in anthropotomy as the 'os laterale linguale,' or 'cornu majus ossis hyoidei;' for this part I have proposed the name 'thyrohyal,' for the reasons assigned in the note (2) to Table I.

The names assigned to the bones of the scapular arch (figs. 5, 22, 23, 24, 25,

* Geol. Trans., vol. v. p. 565. † Bridgewater Treatise, vol. i. p. 176.

23, 50–52) and its appendages (*ib.* 53–58) agree so closely with those which they have always borne as to require no explanation here. The chief surprise of the anthropotomist will be occasioned by their being included amongst the bones of the head. That the upper or pectoral extremity and its supporting arch form actually integrant parts of the occipital segment of the skull, will be proved in the memoir on the general homologies of the bones of the head. I may, here, however, in reference to the terms 'ulna' and 'radius,' request the anatomist to compare the skeletons of the perch or cod with that of the porpoise. The pectoral extremity is in the form of a fin, and in both fish and marine mammal it is applied, in a state of rest, prone to the side of the trunk; in this position it will be seen in the *Delphinus*, that the radius is downward, and the ulna with its projecting olecranon upwards. I take this as the guide to the homology of the two bones that support the carpal series of the pectoral fin in fishes. Cuvier, however, gives the name of 'cubital,' perhaps on account of its angular olecranoid prolongation, to the lower bone, and 'radial' to the upper bone: and in these determinations he is followed by M. Agassiz. Both bones coalesce with the supporting arch in the lophius and some other fishes; and since, in the lophius, two of the carpal bones are unusually elongated, Geoffroy mistook these for homologues of the radius and ulna. The condition of the pelvic member or ventral fin is, in fact, here repeated in the pectoral; there being no homologous segment of thigh or leg interposed in any ventrals between the supporting (pelvic) arch and the fin-rays representing the tarso-metatarse and phalanges. The earlier stages in the development of all locomotive extremities are permanently retained or represented in the paired fins of fishes. First the essential part of the member, the hand or foot, appears: then the fore-arm or leg; both much shortened, flattened and expanded, as in all fins and all embryonic rudiments of limbs: finally comes the humeral and femoral segments; but this stage I have not found attained in any fish. It is with considerable doubt that I place, qualified by a note of interrogation, Cuvier's "troisième os qui porte la nagoire pectorale" as the homologue or rudimental representative of a 'humerus.' Normally, I believe this proximal member of the radiated appendage of the scapular arch not to be distinctly eliminated from that arch in the class of fishes. The Siluroids are examples of a similar confluence of the first segment (preoperculum) of the diverging appendage of the tympanic arch with that arch. With regard to the lower, distal or apical element of the scapulo-coracoid arch, always the largest bone of the arch in fishes, Cuvier's idea that it is the 'humerus,' far less accords with the law of the development, the connections, and the essential nature of that bone, than the more prevalent view, that it represents the clavicle: a view entertained by Spix, Meckel, and Agassiz, by Wagner, who calls it 'vordere Schlüsselbein,' and by Geoffroy, who calls it 'furculaire.' I have, however, been induced to regard the lower element of the scapular arch, in fishes (fig. 5, 52), as homologous with that bone, the 'coracoid,' which progressively acquires a more constant and larger development in descending from mammals to fishes, and which is manifestly a more essential part of the arch than the clavicle, since it is more constant in its existence, and always more completely developed in birds and reptiles; and especially since it contributes more or less of the surface of attachment for the radiated appendage, which the clavicle never does. With reference, also, to the Cuvierian determination of the hæmapophysial portion of the occipital inverted arch in fishes, this is unquestionably as essential an element of the arch as is the 'coracoïde' in other vertebrates; and it is the most important part in the piscine class, in no member of which does it present the slightest approach to the character of

Fig. 5.



Disarticulated bones of the neural arches (N I to IV) and sense-capsules; the hæmal arches (H I to IV) and appendages in diagrammatic outline. Cod (*Morrhua vulgaris*).

a diverging appendage, such as the humerus essentially is, whenever it has an independent existence. By some ichthyotomists, the bone which I call coracoid (*sz*) has received the special name of 'cœnosteon.'

Cuvier's usual judgement and acumen seem to have been in abeyance, when, having determined the rays of the pectoral fin to represent the bones of the hand, and the two bones which support them in fishes to be those of the fore-arm, he concluded that, therefore, the great bone which completed the scapular arch "répondra donc nécessairement à l'humérus."—*Hist. des Poissons*, 4to. i. p. 274. The great anatomist assigns no other reason: but the arch supporting the ventral fin does not necessarily answer to the tibia or the femur, because neither of these segments are interposed between the arch and its appendage—the modified foot*. The scapula of many reptiles, especially of the batrachia, is manifestly, he proceeds to state, composed of two bones. But in those reptiles the arch is completed below by a third bone, which neither Cuvier nor any other anatomist has called 'humerus.' Now Cuvier's 'humerale' in fishes precisely answers to that third bone in reptiles which he rightly calls the 'coracoid' in that class.

The coracoid of fishes being thus determined, it necessarily follows that that inconstant bone, or pair of bones (*ss*) posterior to it on each side, cannot be, as Cuvier, Geoffroy, Meckel and Agassiz have supposed, the representative of the 'os coracoïdien' of the reptile and bird. It holds, indeed, as they have said, the same relative position to the bone *sz*, here called coracoid, which the coracoid in the lizard and bird holds to the clavicle in those animals. But is no account to be taken of the remarkably though normally advanced position of the scapulo-coracoid arch in fishes? Granting, as I shall give evidence to prove in treating of the general homologies of the bones, that the bone (*ss*) called by Cuvier 'coracoïdien' in fishes appertains to a vertebral segment posterior to the occipital one, yet in the extraordinary backward displacement which the true scapulo-coracoid arch undergoes in the air-breathing vertebrates, may not its relative position to that arch become reversed, and the part which is behind in fishes become before in birds? I entertain no unmeet confidence in the correctness of my view of the special homology of Cuvier's 'os coracoïdien' in fishes with the furculum or 'clavicle' of air-breathing vertebrates: the argument against such a view, from its posterior position in fishes, has not, however, the same weight with me as it appears to have had with Cuvier and his followers: and, leaving this as one of the undecided points in special homology, with the proposition of the provisional name of 'epicoracoid' (*epicoracoideum*, Lat.) for the bone in question, I proceed to consider other mooted points of special homology, of which there are better and surer grounds for the determination.

The first discrepancy, demanding special consideration, which meets the eye in the TABLE I. is that which relates to the determination of no. 6. The German authorities regard what I believe to be the homologue of the human 'ala major sphenoidalis' in the cold-blooded Vertebrata, to be the homologue of the 'pars petrosa ossis temporis.' Cuvier recognises the 'grande aile du sphénoïde' in mammals, birds and fishes, but regards my 'alisphenoid' in reptiles as the 'rocher' or 'pars petrosa.' Geoffroy concurs with Cuvier and the German anatomists so far as to view my 'alisphenoid' in the Crocodile as a dismemberment of the petrosal, calling it 'prérupéal;' but he recognises, like Agassiz and Cuvier, the true alisphenoid in fishes, and with them differs in that respect from the German homologists. It does not appear that the alisphenoid has been mistaken for any other bone than the petrosal, and the

* The great Linnæus indicates his appreciation of the homology of the ventral fins of fishes by styling the fishes without those fins 'Apodal.'

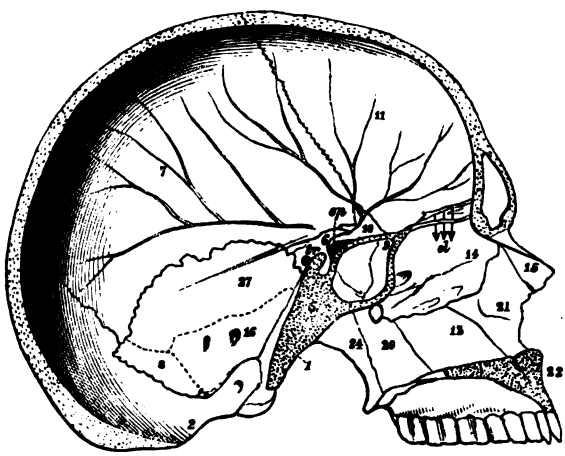
question to be determined, therefore, is, what are the essential characters respectively of the 'alisphenoid' and the 'petrosal' in the vertebrate series?

Those of the *alisphenoid* appear to me to be the following:—1st, its connection below with the basisphenoid and behind with the petrosal, where it forms the forepart of the 'otocrane' or cavity for the reception of that osseous or cartilaginous immediate capsule of the labyrinth or internal organ of hearing: the alisphenoid is also commonly, but not constantly, joined before with the orbitosphenoid, and above with the parietal: it has other less constant connections with the squamosal, the exoccipital, the supraoccipital and the basioccipital: 2ndly, with regard to its essential functions, the alisphenoid protects more or less of the side of the mesencephalon, or (in mammals) of the middle lobe of the hemisphere: it gives exit, by notches or foramina, to the third, and usually, also, to the second divisions of the trigeminal or fifth pair of nerves.

The essential character of the *petrosal* is to envelope immediately the whole of the vascular and nervous tunics of the labyrinth or internal organs of hearing, either in a membranous, a cartilaginous or an osseous state; its histological condition being much less constant than that of the alisphenoid.

On viewing the alisphenoid on the interior surface of the human skull (fig. 6, *a*), it seems to be the least significant and important part of the lateral

Fig. 6.



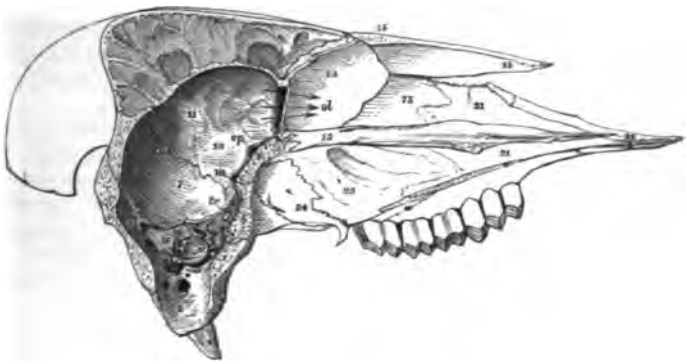
Vertical longitudinal section of the human cranium.

walls of the cranial cavity: it forms their smallest portion: it is much surpassed in extent by the squamosal (*ib.* 27) and the supra-occipital (*ib.* 3), and still more so by the enormously expanded parietal (7) and frontal (11). Nevertheless we find it connected, anchylosed indeed, below to the basisphenoid (5), bounding anteriorly the space into which the petrosal (16) is wedged; connected in front with the orbito-sphenoid (10), and usually articulating by its superior apex with the parietal: I purposely omit the mention of other connections of the alisphenoid in Man which are less constant in the vertebrate series. But it is important to observe, notwithstanding the displacement which the alisphenoid has undergone through the intercalation of the extraordinarily developed squamosal into the lateral walls

of the cranium, that it is still perforated by the third (*ib. tr*) and second divisions of the fifth or trigeminal nerve.

In tracing the alisphenoid downwards through the mammalian series, we cannot but be impressed with the conviction of its true character and importance as an essential part of the cranium, from its constancy in the formation of its walls, and by observing that, whilst the share which the squamosal takes in them progressively decreases,—until in the sheep, for example, it is quite excluded

Fig. 7.

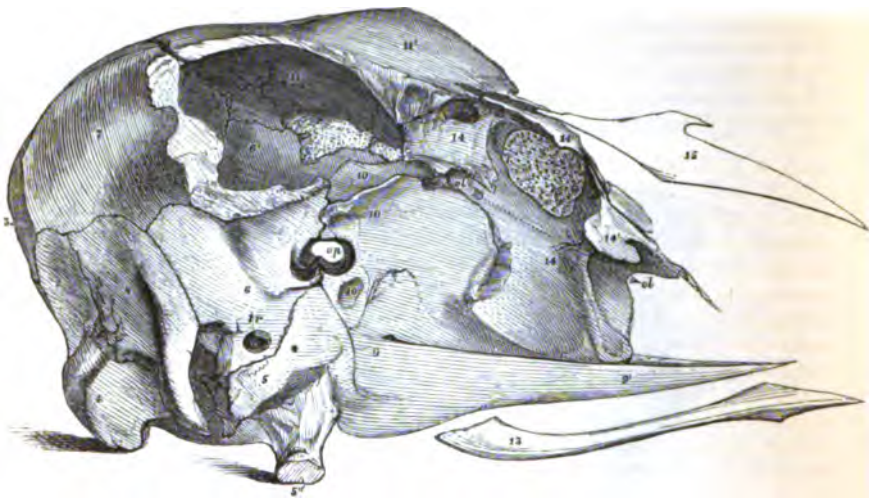


Vertical longitudinal section of the cranium of a sheep (*Ovis Aries*).

from the cranial cavity,—that of the alisphenoid (fig. 7, 6) increases as the cavity itself diminishes in size; and, further, that this increase is not accompanied with any material change in the relative size of the alisphenoid to the basisphenoid. The share which the alisphenoid takes in forming the anterior boundary of the otocrane increases; as does also the extent of its superior connections, especially of that with the parietal (7). It is important, in tracing these modifications, to note, also, the change in the relative position of the foramen ovale in the mammalian series. In Man the foramen ovale (fig. 6, *tr*) is close to the hinder border of the alisphenoid; and in some quadrumanes the third division of the fifth escapes through a notch in the same border. This position of the foramen ovale relates to the alisphenoid being pushed forward by the intrusion not only of a large ossified petrosal (16), but of a still larger squamosal (27). In the sheep, however, the foramen ovale is no longer at the posterior margin; but, the alisphenoid, having retrograded by the recession of the squamosal towards its more normal exterior position in the vertebrate series, the third division of the trigeminal now perforates its middle part (fig. 7, *tr*). It may be observed that, concomitantly with this retrogradation of the alisphenoid, the orbito-sphenoid (*ib.* 10) acquires larger proportional dimensions than in Man (fig. 6, 10).

In the bird the alisphenoid (fig. 8, 6) is recognizable by the repetition of the connections which it presented in the sheep; the squamosal being quite excluded from the cranial parietes, and, indeed, never again presenting itself in the capacity of a cranial bone in any of the oviparous vertebrates. The alisphenoid (fig. 23, 6) is in contact posteriorly with the petrosal (*ib.* 16), which soon becomes anchylosed with it, as well as with the exoccipital (2), mastoid (3), and other bones forming the cavity for its reception, in all birds. The alisphenoid further manifests its true homology in the bird by its other constant character of transmitting the third and also the second or maxillary division of the trigeminal nerve; which divisions, in the young ostrich, I

Fig. 8.

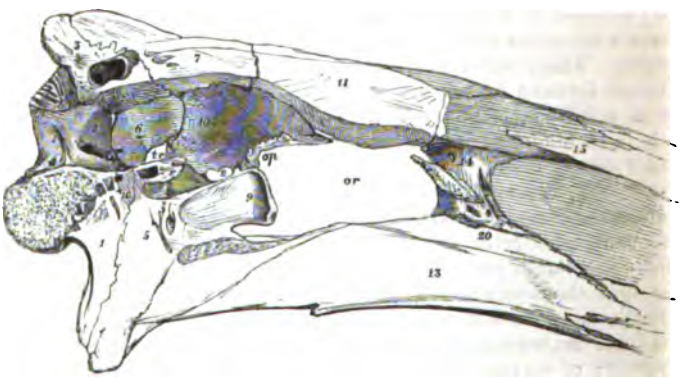


Partly disarticulated cranium of a young ostrich (*Struthio camelus*), natural size.

found distinctly perforating the middle of its lower border (fig. 8, *e*, *tr*). The alisphenoid is deeply impressed by the chief ganglions of the mesencephalon, viz. the optic lobes. The prosencephalon or hemispheres are still defended principally by expanded parietals (*ib.* 7) and frontals (*ib.* 11)*.

In the crocodile these spinal elements of the cranium are much restricted in their development, and a larger proportion of the hemispheres is defended by the orbitosphenoid (fig. 9, 10), which here surpasses the alisphenoid (*ib.* 6) in size. This, however, still performs its essential and characteristic func-

Fig. 9.



Vertical longitudinal section of the cranium of a crocodile (*Crocodilus acutus*).

tions of protecting the sides of the mesencephalon, and giving issue to the chief part of the trigeminal nerve. Owing to the diminution in size of the

* The right frontal has been removed to show better the extent and connections of the orbitosphenoid (10) and the prefrontal (14).

petrosal (16), and the retention by a great proportion of this capsule of the acoustic labyrinth of its primitive cartilaginous state, it occupies a smaller interval between the alisphenoid (6) and exoccipital (2). It no longer protrudes as a large bony wedge (as in figs. 6 and 7, 16) into the cranial cavity, but permits the alisphenoid to come into connection with the exoccipital. The result of this further retrogradation of the alisphenoid, in regard to the relative position of the outlet of the third division of the fifth, is analogous to that which occurs in the sheep. We saw in that mammal, through the recession of the squamosal, the foramen ovale advanced from the posterior to the middle part of the alisphenoid; in the crocodile, through the further removal from the cranial cavity of the interposed petrosal, the foramen ovale is advanced to the anterior border of the alisphenoid; which border, in fact, it notches, the nerve escaping by a common foramen or 'trou du conjugaison' between the alisphenoid and the orbitosphenoid, the hole, however, being principally formed by the alisphenoid (fig. 9, *tr*). This position of the 'foramen ovale' loses all its value as an argument in favour of the petrosal character of no. 6, by analogy with the position of the foramen ovale in man or the ape, when we take into consideration the necessary consequences of the successive withdrawal of the squamosal and true petrosal from the inner surface of the cranium in descending to the reptiles. The orbitosphenoid (fig. 9, 10), notwithstanding its great relative size, retains all its essential characters: it is perforated or notched for the exit of the optic nerves (*op*) and first division of the fifth pair (*s*); it rests upon the presphenoid (9) below, and likewise, through its backward development, partly upon the basisphenoid, and it articulates with the frontal (11) above, and also through the same backward extension with the parietal (7); it constitutes the anterior border of the lateral bony parietes of the cranium, which are interrupted by the orbits, and separated by their interposition in saurians and fishes from the rhinencephalic part of the cranial cavity (at 14, fig. 9). The characters, in fact, of the orbitosphenoid are so clearly manifested in the crocodile, that Cuvier, having been led by the increased share, as compared with mammals, which the crocodile's alisphenoid (fig. 9, 6) takes in the formation of the otocrane, to regard it as the petrosal, and yet perceiving the essential characters of the orbitosphenoid in the bone (*ib.* 10) anterior to it, was driven to the conclusion that that bone represented both orbitosphenoid ('aile orbitaire du sphénoïde') and alisphenoid (aile temporale du sphénoïde). The cold-blooded crocodile, however, is not exactly the animal in which we should expect to find so unusual an instance of obliteration of sutures, as that between the alisphenoid and orbitosphenoid*. The actual and most characteristic modification of the orbitosphenoid in the crocodile's skull, is its retrogradation together with the alisphenoid, or rather the maintenance of its normal connection therewith by increased antero-posterior development, whereby it comes into communication above with the parietal (7) and below with the basisphenoid (5); whilst the alisphenoid, in like manner, gains a connection with the supra-occipital (3) above and the basi-occipital (1) below; although it still retains its more normal relations with the parietal, and rests in great part on the basisphenoid (5), as the orbitosphenoid rests in great part upon the pre-sphenoid (9.) The superior connec-

* No one better appreciated the characteristic persistence of the sutures in the crocodile than Cuvier, when his attention was not diverted from it by a favourite hypothesis. "Le crocodile a cela d'avantageux à l'étude de son ostéologie, que ses sutures ne s'effacent point, du moins n'en a-t-il disparu aucune dans nos plus vieilles têtes," is the remark with which he commences his article on the determination of the bones of the head of that reptile (Ossemens Fossiles, 4to. v. pt. ii. p. 69): but at p. 76, a suture is assumed to be effaced, which is present in most mammals and all cold-blooded vertebrates, where a wider space does not intervene between the alisphenoid and orbitosphenoid.

tions of the orbitosphenoid and alisphenoid are always less constant than their inferior ones. By these latter characters, and still better by their nerve-outlets and their relations to the primary divisions of the encephalon, are they rightly and truly determinable. The German authors who have followed Cuvier in his views of the special homology of the alisphenoid in reptiles, are more consistent than the great French anatomist in regard to the alisphenoid of fishes. Dr. Hallmann, accepting Cuvier's characters of the petrosal, taken from its internal position and lodgement of the whole or part of the labyrinth*, naturally applies them to the alisphenoid in fishes, and adds to the grounds for regarding that bone as the 'petrosal,' that it is in some fishes perforated by the opercular branch of the great trigeminal nerve†. But, admitting the homology of the opercular nerve with the facial nerve of mammals, yet its wider homology and essential character as a motor division of the great trigeminal nerve must not be lost sight of: its origin in close contiguity with the great sensory portions of the trigeminal in fishes accords better with the character of that nerve as the great spinal nerve of the brain, than it usually presents in higher classes; and it is surely no important departure of the alisphenoid from its normal character, that it should give exit to both motory and sensory divisions of the great nerve with which it is so intimately associated from man down to the fish. Indeed, the progressive withdrawal of the bony petrosal from the interior of the skull and the concomitant backward extension, or retrogradation of the alisphenoid, ought to prepare us to expect that nerves which traverse the petrosal in mammals should perforate the alisphenoid in reptiles and fishes. And so we find in the carp that the glosso-pharyngeal even perforates the posterior border of the alisphenoid; but its origin close to the acoustic and facial nerves in fishes diminishes the force of the argument which might be drawn from this exceptional perforation, in favour of the petrosal character of the alisphenoid. I concur entirely with Cuvier and M. Agassiz in their determination of the alisphenoid in fishes; but, if the great share which that bone in reptiles (figs. 9 and 10, *e*) contributes to the formation of the otocrane, if the anterior position of the foramen ovale, and the superior connection of the bone with the supra-occipital, are proofs (as Cuvier believed) of its homology with the petrosal in the class *Reptilia*, they ought also, as Hallmann and Wagner contend, to establish the same special homology of the bone (*e*) in the class *Pisces*. But none of these are essential characters of the petrosal. The petrosal is a *contentum* and not a *paries*, or any part of the parietes of the cranial chamber or otocrane lodging the organ of hearing: it is the outermost tunic, membranous, gristly, or bony, of the labyrinth or essential part of the acoustic organ. Had the above-cited anatomists clearly appreciated the general homology of the petrosal, they could scarcely have failed to detect its special homologies in the vertebrate series. Cuvier was evidently guided to the true determination of the alisphenoid in fishes, less by its own essential characters, than by observing in certain fishes, the perch and cod for example, a partial ossification of the acoustic capsule, to which, therefore, he assigned the name 'rocher.' And, having thus satisfied himself of the existence of the homologue of the 'pars petrosa,' &c., he could not but assign to the bone which rested below upon the basisphenoid, which protected laterally the optic lobes and gave exit to the third division of the trigeminal nerve, the name of 'grande aile du sphénoïde.' But all these characters equally coexist in the bone which Cuvier calls 'rocher' (petrosal) in the crocodile and other reptilia. He was not aware, however, that in both gavials and crocodiles a distinct ossicle, the veritable homologue of the intra-cranial pyra-

* Ossemens Fossiles, 4to, t. v. pt. i. p. 81.

† Der vergleichende Osteologie des Schläfenbeins, p. 64.

midal-shaped petrosal of mammals and birds, makes its appearance between the alisphenoid, exoccipital and basioccipital, as at 16, fig. 9. Here, however, it is necessary to offer a few observations on the sense in which I use the term 'petrosal' as applied to that ossicle.

The petrosal, properly so called, considered in its totality, as the immediately investing capsule of the labyrinth or internal organ of hearing, is wholly cartilaginous in many fishes and saurians, and in all batrachians, ophidians and chelonians, and is contained in a cavity or orbit (otocrane) which most, or all of the elements of the occipital and parietal vertebræ concur in forming. A part of the ear-capsule remains cartilaginous in the crocodile; but several portions become ossified around the semicircular canals and rudimental cochlea, which ossifications contract slender adhesions to the smooth otocranial surfaces of the supraoccipital, exoccipital and alisphenoid; and to one of these portions (on the principle on which Cuvier applies the term 'rocher' in fishes) the name petrosal might more particularly be given, as it is more distinct and moveable than the other partial ossifications of the capsule, and contributes to form the 'meatus internus' towards the cranial cavity, surrounds nearly the whole of the 'fenestra rotunda', and one-half of the 'fenestra ovalis' towards the tympanic cavity. Looking upon the inner surface of the lateral walls of the cranium (as at fig. 9), one sees at the bottom of the T-shaped suture* uniting the otocranial laminæ of the exoccipital, alisphenoid, and supraoccipital bones, a fourth osseous element (16), presenting a convex extremity towards the cranial cavity, and completing, with the exoccipital, the lower half of the foramen for the nervus vagus. If this little bone be pressed upon with a needle or probe, it yields and moves, being divided by smooth harmoniæ from both the exoccipital (2) and alisphenoid (8).

The protuberance in question, which thus projects into the cranial cavity, is the rounded angle of the border of the inferior plate of the petrosal, which joins the exoccipital. This lower horizontal plate of the petrosal forms the upper wall of the 'fissura lacera posterior,' and the lower wall of the 'fenestra cochleæ': the fore-part of the horizontal plate bends upwards, twisting and expanding into a vertical oval plate, articulated by its anterior surface to a corresponding sutural surface of the alisphenoid. The lower margin of this plate forms the upper boundary of the 'fenestra cochleæ,' and is continued into a thin plate of bone which divides the 'fenestra cochleæ' from the 'fenestra vestibuli' above. This thin plate of the petrosal joins and is usually anchylosed to the exoccipital: it is the only part of the true petrosal noticed by Cuvier, who describes it as a slender filament of bone which separates the two fenestræ†. Seen edgewise, looking into the tympanic cavity, the plate appears like a filament: and this plate forms the sole connection, when any exists, between the petrosal and the exoccipital. I have always found the sutures persistent between the petrosal and the alisphenoid. The upper border of the 'fenestra vestibuli' is formed by a petrosal, or rather otocranial, process of the alisphenoid.

The part (fig. 9, 16) entering into the formation of the lateral walls of the brain-case, and which is here specially indicated by the name of 'petrosal,' seems to have been overlooked: it is, however, relatively to the alisphenoid or exoccipital, as large as is the petrosal (Cuvier's rocher) in the perch: it has a true osseous texture, and is quite distinct from the lenticular mass of calcareous matter in the adjacent cochlear chamber which Cuvier compares to starch ('amidon durci').

* Suture à trois branches, Cuvier, *l. c.* p. 165.

† Du côte de la caisse la paroi est percée de deux fenêtres transversalement oblongues et séparées par un filet mince." *l. c.* p. 82.

Neither the figure of the interior surface of the cranium of the crocodile, which Spix gives as that of the Nilotic species in his great 'Cephalogenesis,' tab. ii. fig. 6; nor the figure given by Geoffroy of the skull of his *Crocodilus suchus* in the 'Annales des Sciences,' tom. iii. pl. 16, fig. 2; nor that of the *Crocodilus biporcatus*, which illustrates the later memoir by the same author in the 'Mémoires de l'Académie Royale des Sciences,' t. xii. (1833), pl. 1, fig. 2.; nor that (if it be an original figure) published by Dr. Hallmann in his 'Comparative Anatomy of the Temporal Bone' (taf. iii. fig. 49), give any indication of this, in the determination of the homology of the alisphenoid and petrosal, most significant and important ossicle. The proof of its normal character will be afforded by comparisons of the description and figure of the part here given with a section of the cranium of any true *Crocodilus*, *Alligator* or *Gavial*. In the latter, the otocranial plates of the alisphenoid, exoccipital and supra-occipital, project considerably into the cranial cavity. Any one of these plates might be called 'petrosal,' for such reasons as have induced Cuvier to apply that name to the alisphenoid in the crocodile and other reptiles*. We find, indeed, that Geoffroy has applied the equivalent term, by turns, to each. But the true idea of the petrosal should include all those gristly and bony parts of the immediately investing capsule of the labyrinth which occupy the otocranial excavations of the exoccipital, supraoccipital and alisphenoid; and as the ossified portions of the true petrosal, in the crocodile, usually contract a bony union with the parietes of the otocrane, all these bony portions of the immediate capsule of the labyrinth might be called 'petrosal processes' of the bones to which they respectively adhere. That portion which unites to the exoccipital is attached by two lamellæ; it forms a great part of the cochlear cavity, the lower half of the posterior semicircular canal and the hinder half of the external or upper semicircular canals: that plate which belongs to the supra-occipital is attached to its otocranial surface by three points, and forms the upper third part of the anterior semicircular canal and the crus of the posterior canal which communicates therewith: that part which adheres to the alisphenoid forms the anterior crus of the anterior (in Man superior) semicircular canal and the anterior beginning of the external canal. The proper and usually distinct bony portion of the petrosal (fig. 9, 16), which articulates with both alisphenoid and exoccipital, forms part of the 'meatus internus,' nearly the whole of the 'fenestra cochleæ,' and half of the 'fenestra vestibuli': it can only be regarded a 'petrosal process' of the exoccipital by virtue of the very limited anchylosis occasionally contracted by the thin plate dividing the two 'fenestræ,' along with the true petrosal process of the exoccipital above described.

If we compare with the inner wall of the crocodile's cranium that of an ophidian, the python for example (fig. 10), we shall find the walls of the 'otocrane' or chamber of the labyrinth to be contributed by the exoccipital, (2) supra-occipital (3) and alisphenoid (6) in nearly equal proportions; the basioccipital (1), also, being ac-

Fig. 10.

Cranium of a python partially bisected. Natural size.

* Ossemens Fossiles, 4to. 1824, v. ii. pp. 81, 180, 258.

cessory to the formation of the floor of the ear-chamber: the three principal bones are united, as in the crocodile, by a triradiate suture. The petrosal, which, like the squamosal, was gradually more and more withdrawn and shut out from the cranial cavity, as we decended from mammals, now entirely disappears from view: and it retains its primitive cartilaginous state in serpents as it does in chelonians, lizards and batrachians. The essential characters of the exoccipital (2) are manifested by its relative position and connections; by its affording exit for the vagal (*v*) and hypoglossal (*hg*) nerves, and by its protecting the sides of the epencephalon. The alisphenoid (6) is not less clearly indicated by its constant and essential characters; it rests below upon the basisphenoid (5), it articulates above with the parietal (7), and behind with the cartilaginous petrosal; but the otocranial plate being, as in the crocodile, unusually extended backwards, unites with the basioccipital (1), exoccipital (2) and supraoccipital (3), in almost equal proportions, and becomes directly perforated by the acoustic nerve (*ac*). Its chief foramen (*tr*), however, is, as usual, that which answers to the foramen ovale in the human alisphenoid, and which gives passage, as in fishes, to the great third division of the fifth, and to the branch which is homologous with the contribution by the fifth to the 'nervus lateralis' in many fishes, and at the same time with the nerve called 'chorda tympani' in anthropotomy.

In the frog I have given an external view of the alisphenoid (6) and the cartilaginous petrosal (10) in their undisturbed connections, in fig. 13, with the surrounding bones. The alisphenoid is here perforated, as in Man, by both a foramen ovale and foramen rotundum (*tr.*): it forms posteriorly the fore-part of the chamber for the cartilaginous petrosal, and usually coalesces with the mastoid (8), which overarches the petrosal: the back wall of the otocrane is contributed, as usual, by the exoccipital (2); the floor by the homologue of the coalesced basisphenoid and basioccipital. Had the outer part of the petrosal (10) been the seat of a partial ossification, a bone would have resulted corresponding precisely with Cuvier's 'rocher' in the cod and perch: but the immediate capsule of the labyrinth retains the same histological condition in the batrachia as it does in the carp and pike, and as in the salamandroid polypterus and lepidosteus: in the latter fish, at most, the only ossified part of the petrosal forms a small bony cup covering the posterior extremity of the outer semicircular canal*.

The attention of the justly celebrated ichthyotomist of Neuchatel appears to have been too exclusively occupied with the persistent embryonic condition of the 'petrosal' in these highly organized fishes, to gain that true and clear idea of the essential nature of the petrosal of which its partial ossification in the perch and cod is indicative. Adopting the opinion of Cuvier, in preference to that of Meckel and Hallmann, touching the special homology of the alisphenoid, M. Agassiz originally diverged into the opposite extreme of repudiating altogether the existence of a petrosal in the class of fishes. Thus, he says, "Il devrait suffire ce me semble de voir l'organe de l'ouïe présenter des modifications graduées dans toute la série des vertèbres, pour se convaincre que le *rocher* n'existe pas du tout chez les poissons, par plus que les osselets de la cavité du tympan. S'il y avait un *rocher* chez les poissons, ce devrait être un os qui entourerait le labyrinthe et les canaux semicirculaires; mais nous avons vu que ces parties de l'oreille interne se trouvent dans la cavité du crâne sans enveloppe osseuse particulière, et protégées seulement par les parois des os qui entourent le rocher, la ou il existe†."

* This condition answers to that in the human embryo of about the fourth month, in which a light porous bony crust begins to be formed upon the cochlea and semicircular canals commencing with the outer and upper ones, the rest of the petrosal being cartilaginous.

† Recherches sur les Poissons Fossiles, tom. v. p. 66.

M. Agassiz is perfectly accurate in his character of the petrosal, according to its relative position, as completely investing the entire labyrinth (of which, by the way, the semicircular canals are an integrant part in all vertebrates and form almost the whole in fishes); but he takes a narrow view of its histological characters. The sclerotic is not less essentially a sclerotic in the shark, where it is cartilaginous, than it is in the cod, where it is osseous; neither is it less the eye-capsule and homotype of the petrosal in the mammal because it retains the earliest histological condition of the skeleton, viz. that of a fibrous membrane. And, in point of fact, in those fishes where the essential parts of the internal organ of hearing appear to be protected solely by the parietes of the bones, which, in the animals where the petrosal is ossified, or, as M. Agassiz expresses the fact, 'exists,' surround such petrosal, the vascular and nervous parts of the labyrinth are actually in such fishes more immediately enveloped by the petrosal in its membranous or cartilaginous states. What is peculiar to the petrosal in fishes is, that it is never entirely ossified; and, furthermore, that whenever it is partially ossified, the bony part is external and appears on the outside of the skull instead of the inside, as in the crocodile and birds.

In the chelonia, a larger proportion of the petrosal intervenes between the alisphenoid and exoccipital upon the inner wall of the cranial cavity than in the crocodile; but it is wholly cartilaginous. In the bird, on the contrary, the whole petrosal capsule of the organ of hearing soon ossifies and becomes firmly anchylosed to the parts of the exoccipital, mastoid, alisphenoid and basisphenoid that form its primitive chamber or otocrane; owing, however, to the larger relative size of the ossified part of the proper capsule (petrosal proper) which penetrates the cranial cavity, none of the surrounding bones which contribute accessory protection, have received the name of 'rocher,' or *pars petrosa*. It is chiefly from not recognizing or appreciating the general nature or homology of the 'petrosal' that Cuvier failed to perceive its special homology in reptiles. Speaking of the skull of the crocodile, he says that the petrosal, or 'rocher,' is not less recognizable than the 'tympanic' and other so-called dismemberments of the temporal by its internal position, by its lodging a great part of the labyrinth, and by its contributing essentially to the formation of one of the fenestræ (*l. c.* p. 81). But the part in the crocodile which I regard as homologous with Cuvier's 'rocher' in the perch, is more completely internal in position than is Cuvier's so-called 'rocher' in the crocodile: it contributes a greater share to the formation of the 'fenestra vestibuli,' and it forms almost the whole of the 'fenestra cochleæ.' It is not true of the alisphenoid (Cuvier's '*rocher*') in the crocodile, that it lodges a great proportion of the labyrinth*: the otocranial or petrosal process of the alisphenoid lodges a part only of the anterior semicircular canal, and no part at all of the other semicircular canals. The exoccipital is that tributary of the otocrane which lodges the major part of the labyrinth; it contains, for example, parts of two semicircular canals, and the rudimental cochlea: and, when the middle, usually distinct part of the petrosal is joined to it, the exoccipital may be said to form the whole 'fenestra cochleæ' and a greater part of the 'fenestra vestibuli.' We see, then, that the characters by which Cuvier deems his 'rocher' to be so easily recognizable, are more prominent in the exoccipital than in the alisphenoid: and the choice of the latter by Cuvier as the representative of the 'rocher,' seems chiefly to have been influenced by the more obvious and unmistakeable essential (neurapophysial) characters of the 'occipital latéral' (fig. 9, 2), whilst the accessory character which this bone derives from its lodging and becoming confluent with part of the true petrosal, was not allowed

* "Il loge en grande partie le labyrinthe," *l. c.* p. 81.

to prevail, as in the case of the alisphenoid, in the determination of its special homology.

The supraoccipital, by virtue of its internal position and lodgment of part of the labyrinth, has equal claims to the name of 'rocher,' according to the Cuvierian characters of that bone, and Geoffroy St. Hilaire did not make a less arbitrary choice in singling out this element as 'le seul rupéal*,' than Cuvier did in choosing the alisphenoid, or, as any other anatomist would do in preferring any other element of a cranial vertebra in the crocodile to represent the ossified ear-capsule of the fish or mammal, because portions of that ossified capsule are protected by, or have coalesced with, such vertebral elements. Had Cuvier looked beyond the special homology of the bones of the head of the crocodile, and permitted himself to appreciate their higher and more general relations, he could scarcely have failed to perceive the correspondence of his so-called 'rocher' in batrachians, ophidians, chelonians and saurians, to the bone which he so well recognizes as 'the great wing of the sphenoid' in the perch and cod-fish.

The Mastoid.—In the human embryo of the fifth month a centre of ossification is established on the outer surface of the mass of cartilage occupying the interspace between the basioccipital (fig. 11, 1) and exoccipital (2) below, the tympanic (28) and squamosal (27) in front, the supraoccipital (3) behind, and the parietal (7) above: this mass of cartilage incloses the membranous labyrinth, about which a light osseous crust has begun to be formed; and, from the centre (8) established near the outer border of the posterior semicircular canal, ossification radiates to complete that part of the cranial parietes, which, in the adult skull, is impressed on its inner surface by the great venous channel called 'fossa sigmoidea,' and developes from its outer surface the 'processus mastoideus.' The primitive independence of the base of this process, which Kerkringius so clearly and accurately delineates in his *tab.* xxxv. *fig.* iii. as the posterior of his 'tria petrosi ossis distincta ossicula†,' is a fact of much more significance than its brief and transitory manifestation would lead the anthropotomist to divine. The coalescence of the primitively distinct mastoid with the ossifying capsule of the labyrinth is very speedy, being usually complete before the fœtus has passed its fifth month, and a composite 'petro-mastoid' bone is thus formed, which, retaining its individuality in monotremes, marsupials, ruminants and many rodents, proceeds to coalesce with the additional elements of the 'temporal' bone in man, and with other surrounding cranial bones in birds. In the cold-blooded vertebrata, the mastoid retains, with a few exceptions, its primary embryonic distinctness, as an independent element of the skull. In tracing the modifications of this element downwards from man, we find the external process from which its anthropotomical name originated,

Fig. 11.

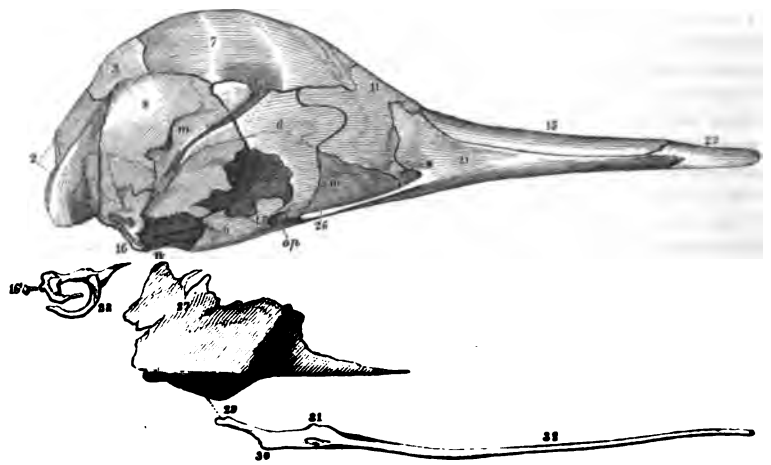
Skull of the human embryo; fifth month. Natural size.

* Annales des Sciences Naturelles, tom. iii. 1824, p. 271, pl. 16.

† Spicilegium Anatomicum, 4to. 1670, Osteogenia Fœtuum, p. 269.

inconstant, its functions being transferred in many mammals to another process, sometimes udder-shaped, sometimes of great length (fig. 24, 4), but which is developed from the exoccipital, and is represented in the human skull by the 'eminentia aspera,' &c. of Soemmerring (Table I. 4), and by the "scabrous ridge extended from the middle of the condyle towards the root of the mastoid process" of Munro (*op. cit.* p. 72); but sometimes also here developed, as a rare anomaly, on one or both sides, into a process like a second but smaller posterior mastoid*. The more constant and essential characters of the mastoid are its contribution to the walls of the acoustic chamber, carried to anchylosis with the petrosal in birds and mammals, and its sutural connection in the latter with the exoccipital, parietal, and squamosal (the squamo-mastoid suture becoming obliterated in many species, *e. g.* the hog, fig. 24, 8, 27): it is also grooved, notched or perforated by a greater or less proportion of the lateral venous sinus, whether this is continued to the 'foramen jugulare,' as in man, or sends a large division to escape by the 'meatus temporalis' which forms the large orifice between the mastoid and squamosal above the meatus auditorius in the horse and ruminants, and which directly perforates the mastoid in the echidna (fig. 12, *m*).

Fig. 12.



Partially disarticulated cranium of the *Echidna setosa*. Natural size.

It is important to keep these essential characters steadily in view, and to avoid giving undue importance to the apophysial character of the mastoid, which has led to so common a transference of its name, in the great osteological works of Cuvier and De Blainville, to a quite distinct element (paroccipital) of the cranial walls†. It is necessary, also, to be prepared for that change of the

* The continuators of Cuvier make mention of an example of this kind and propose the name of 'paramastoid' for the process (Leçons d'Anat. Comp. ii. (1837) p. 312). I have observed it in the skull of a New Zealander and in that of an Irishman, preserved in the Museum of Anatomy in Richmond Street, Dublin. Believing it to be the homologue of the 'paroccipital' (4), which is developed independently in chelonia and most fishes, I retain that name for it: it must not be confounded with that angle of the occipital which projects into the 'foramen jugulare' in the human skull, and which has received the name of 'processus jugularis,' in some systems of anthropotomy.

† How essential a correct view of special homology becomes to the appreciation of the

connections of the mastoid, which results from the gradual withdrawal, in the mammalian class, of the squamosal from the proper cranial walls. With much inconstancy of relative size in the mastoid, of which the dugong and the walrus offer two extremes, we discern upon the whole a progressive increase in descending through the mammalian class: in the walrus, for example, the mastoid, or petromastoid, forms as large a proportion of the outer lateral walls of the cranium as does the squamosal; and, in the sheep, the removal of the squamosal exposes the connection of the petromastoid with the alisphenoid,—a return to a relation common in the oviparous vertebrata: it is shown from the inner side of the cranium in the sheep, in fig. 7, 16 and 6. The mastoid of the echidna (fig. 12, 8) presents a most interesting and instructive combination of both the modification of expansion and of that of direct union with the alisphenoid (6), which is here effected by the mastoid plate independently of the petrosal (16). In fig. 12 these characters are well exposed by the removal of the squamosal 27, and tympanic 28, which retain their primitive independence throughout life in the echidna. If now we compare the bone 8 and 16 with the cartilaginous and osseous mass 8 and 16 in the skull of the human embryo (fig. 11), and allow for the change produced in the position of the alisphenoid (6) by the gradual withdrawal of the squamosal (27), traceable in the intervening forms of mammalia, the special homology of the petromastoids at the two extremes of the mammalian class will be obvious and unmistakeable. The bone 8 and 16 in the echidna, fig. 12, is connected below and behind with the basi-occipital and exoccipital (2), behind and above with the supraoccipital (3) and parietal (7), in front with the tympanic, the squamosal, and also, as a consequence of the modified position of the latter and of its own increased development, with the alisphenoid (6). All the connections, save that with the alisphenoid, are identical with those of 8 and 16 in the human embryo; and the supervening alisphenoidal connection in the echidna affords an additional light to the determination of the bone in the lower vertebrata, since it is a consequence of the progressive advance to a lower (oviparous) type, in the descent through the mammalian scale. In regard to the essential functions of the petromastoid, we find the petrosal portion inclosing the membranous labyrinth, and the mastoidal portion giving exit to the blood from the great lateral venous sinus and supporting the tympanic*. It will be unnecessary to dwell further on the broad and obvious characters by which the homology of the bone 8 and 16 in the echidna is established with the equally independent petromastoid in the sheep and walrus, and with the petromastoid portion of the human 'temporal bone.'

The continuators of the 'Leçons d'Anatomie Comparée,' influenced by the large proportional size of the petromastoid in the echidna and the share which it consequently takes in the formation of the cranial parietes, supposed it to be the squamosal:—"le véritable temporal, qui n'aurait pour toute apophyse zygomatique qu'un très petit tubercule près de la facette glénoïde,"

higher law of general homology may be learnt from the application by Cuvier of his idea of the mammalian mastoid to the refutation of the vertebral theory of the skull. "On a aussi trouvé quelque rapport entre l'apophyse mastoïde qui, dans la plupart des animaux, appartient à l'occipital, et l'apophyse transverse de l'atlas et des autres vertèbres; sur quoi il faut remarquer que ces rapports sont moindres dans l'homme à certains égards que dans les quadrupèdes, puisque l'atlas n'y a ordinairement qu'une echancrure pour le passage de l'artère, et que l'apophyse mastoïde y appartient entière au rocher."—Resumé sur le question—'Le crâne est-il une vertèbre ou un composé de trois ou quatre vertèbres?' Leçons d'Anatomie Comparée, t. ii. (1837) p. 711.

* In the article 'Monotremata,' Cyclopædia of Anatomy and Physiology, 1841; influenced, then, by the absence of the external character of the process, I described the petromastoid as the petrous bone.

op. cit. t. ii. (1837) p. 377. This tubercle is the rudiment of the mastoid process, which is so largely developed in birds, and which, in the echidna, overhangs the tympanic cavity. There is no glenoid articular surface upon the bone 8 and 16. We find, on the other hand, the squamosal under its proper mammalian form and connections, with a long and slender zygomatic process, and performing the function, peculiar to the class Mammalia, of supporting the mandible by the true glenoid articular surface in the echidna (fig. 12, 27).

Dr. Köstlin, whose painstaking and minutely accurate description of the osteology of the vertebrate skull renders his conclusions as to their homologies worthy of respectful consideration, concurs with me in regard to the squamosal (27) of the monotremes, but regards the bone 8–16 in the echidna as a dismemberment of the alisphenoid. In no mammal, however, do we find the alisphenoid concerned in immediately protecting the semicircular canals—this is the function of the petrosal: in neither mammal nor bird does the alisphenoid extend its connections so far back as to the basi- ex- and supra-occipitals. In the echidna, as in every other mammal and bird, the alisphenoid (6) exists, exclusively exercising its essential function of transmitting the third division of the fifth pair by the large vacuity (*tr*) and with its normal connections modified only, as in the sheep and some other inferior mammalia, through the recession of the squamosal, by joining the mastoid, in addition to those which it unites with in man. I confess that I can perceive no other gain to anatomy by Dr. Köstlin's new determination of 8 and 16 in the echidna as 'hintere Abtheilung des Schläfenflügels' or 'hintern Schläfenflügel*' (posterior alisphenoid), than an additional phrase to the synonyms of the mastoid.

The discussion of the homologies of this bone under its modifications in the mammalia, and especially in the monotremata, will not be deemed superfluous or too detailed, when it is remembered how valuable a key the cranial organization of the implacental monotremes with their bird-like heads becomes to the comprehension of the modifications of the cranial structure in birds themselves. If we pass from the comparison of the echidna's skull, as represented in fig. 12, to that of the ostrich (fig. 8), we shall find there a bone (8) articulated in front to the alisphenoid (6), behind to the exoccipital (2), below to the basi-occipital and basi-sphenoid, above to the parietal 7, and coalescing by its inner surface with the petrosal. The sole modification of note in regard to connective characters, as compared with the mammalian petromastoid, is the loss of the connection with the squamosal, for which we have been progressively prepared by the conditions of that bone in rodents, ruminants and monotremes. In the bird this least constant element of the cranial walls (fig. 21, 27) has undergone a further degradation, is now dismissed entirely from any share in the formation of even the outer surface of the cranial parietes, and is reduced to its mere zygomatic form and function, serving exclusively to connect the jugal (fig. 21, 26) with the tympanic (28); which function it performs in the echidna and in man, besides other superadded offices arising out of its peculiarly mammalian expansion into a scale-like lamina, or as compensatory of the reduction of the tympanic bone. Dr. Hallmann, however, in his elaborate monograph on the temporal bone, considers the bone 8 (fig. 8) to be the squamous or zygomatic element, and cites the following characters of the bone, in the young cassowary †, as establishing its homology with the squamosal:—"its junction above with the parietal, in front with the alisphenoid and post-frontal and behind with the occipital; also its formation of the upper border of the meatus auditorius externus, and its

* *Op. cit.* pp. 29, 126.

† Die vergleichende Osteologie des Schläfenbeins, p. 8. pl. 1. fig. 5.

contribution of the articular surface for the tympanic bone," which surface he regards as homologous with the glenoid cavity of the squamosal for the lower jaw in mammals.

Cuvier, whose homology of no. s he thus adopts, describes it in the bird as being on the outer side of the parietal, advancing also to beneath the frontals, occupying the region of the temporal fossa and giving origin to the temporal muscle, and as forming the superior border of the tympanic cavity. "The temporal fossa," adds Cuvier, "is in great part excavated in the temporal bone, and is bounded behind by a special process which might be regarded as the analogue of the zygomatic did it not remain far removed from the malar bone*." The annotators add, "that there are some species of bird in which, nevertheless, such zygomatic process does approach very close to the jugal†."

First, then, with regard to the character which appears to have most weighed with Cuvier, from his twice citing it in the above brief definition of no. s,—the marks of the origin of the temporal muscle. To conclude that the bone impressed by the so-called 'temporal fossa' in the skull of the bird, is therefore the temporal bone, because such fossa impresses a bone called 'temporal' in the mammal, is an example of that fallacy which logicians call arguing in a circle. The two propositions by no means reciprocally prove each other. Suppose, for example, that the bone no. s in the bird had been determined, by way of ascensive comparison from the fish (fig. 5) and crocodile (fig. 16), to be the homologue of the bone no. s in those animals, which we will assume to have been rightly called 'mastoid' by Cuvier, and that he had arrived at the determination of no. s in the bird by this surer method, than by the descent from placental mammals; and supposing that, having thus recognized no. s as the mastoid, the fossa and muscle with which it is impressed in the bird had been called 'mastoidal' instead of 'temporal'; then, ascending to the mammalian cranium, Cuvier might with equal reason have said that the bone 27, figs. 11 and 22, was the 'mastoid,' because it occupied the region of the mastoidal fossa and gave origin to the mastoidal muscle. The origins of muscles are not, however, sufficiently constant to be included amongst the characters of connection or function determinative of special homologies. The transference of the 'sterno-mastoideus' from the true mastoid process (Man, Carnivora and Rodentia) to the angle of the mandible (horse), and to both this part and the second cervical vertebra (Ruminants), shows that the attachments of a muscle must be determined after the recognition of the bone, and not the homology of the bone by muscular attachments. With the very case in question the uncertainty of the character is illustrated: in the skull of the ostrich, for example (fig. 8), the temporal fossa is chiefly formed by the conjoined portions of the parietal (7) and alisphenoid (8), which intervene between the mastoid (3) and the post-frontal, the mastoid forming not more of the posterior part of the fossa than the post-frontal does of the anterior part. Dr. Hallmann probably appreciated the unsoundness of the argument from the muscular impression, since he does not cite it; he repeats, however, the character adduced by Cuvier, from the relation of no. s to the tympanic cavity, or as Hallmann expresses it, the meatus auditorius (äussern Gehör öffnung), the value of which therefore I next proceed to consider.

In the skull of the ostrich, with the tympanic bone and ear-drum in place, the upper border of the meatus, as defined by the periphery of the membrana tympani, is formed, not by no. s, but by the tympanic anteriorly, and by the paroccipital process (4) posteriorly. When the tympanic bone and membrane are removed, then the descending process of no. s overarches the

* Leçons d'Anat. Comp. ii. (1837), p. 580. † *Ib.* p. 581.

upper and forepart of the tympanic cavity so exposed. So much for the facts of the argument*.

We may next ask, Is the formation of the upper boundary of the meatus externus an essential character of the squamosal in mammals; or is it not rather a secondary consequence of the expansion and application of that bone to the side of the cranium in this particular class? If we were desirous of obtaining a homological character by comparison of the contour of the meatus externus or the tympanic cavity in mammals and birds, ought we not rather to select the lowest and most ornithoid of mammals, as best calculated to throw light upon the real nature of the modifications of this part of the skull in the respective classes? In the echidna, then, we find that the squamosal does not form the whole of the superior border of the shallow tympanic cavity, but that the mastoid forms the posterior half of that border, and sends a short obtuse process downwards (at 10, fig. 12), which overhangs the cavity and gives attachment to the tympanic (ss). Behind the mastoid is the exoccipital. Now in birds the antero-posterior extent of the cranium between the exoccipital and post-frontal bones is much shortened as compared with mammals, and this modification I interpret as the result, in a great degree, of the entire removal of the squamosal from the cranial parietes. Of the homology of no. 4 as a part of the exoccipital there has been no question, although its development, and the share it takes in the lateral parietes of the head, is increased, as compared with most mammals, rather than diminished. The exoccipital constantly unites anteriorly with the mastoid in mammals, from man down to the echidna; but the extension of the squamosal backwards to articulate with the exoccipital is far from being a constant character in mammals. We ought on that ground therefore to conclude that the bone 8, which articulates with the fore-part of the exoccipital in the bird, is the 'mastoid,' rather than that it is the 'squamosal.' It overhangs the tympanic cavity by a longer or shorter process; but being more advanced in position, partly by the development of the exoccipital behind, and the non-interposition of a squamosal between it and the alisphenoid in front, it overarches the middle of the upper instead of the posterior part of the upper border of the tympanic cavity in the bird; but it is still in great part posterior to the tympanic pedicle, a relative position which is foreign to the squamosal. The process of no. 8 resembles the mastoid process in mammalia, inasmuch as it terminates freely in most birds; and in those, the parrot for example, in which it joins another process to form a zygoma or bridge over the temporal fossa, that process answers to the post-frontal, the very bone which the mastoid similarly joins in the crocodile, and does not answer to the malar bone, which the squamosal joins in both mammals and crocodiles.

The mastoid always coalesces with the petrosal, rarely with the squamosal, in the mammalia; such coalescence is therefore a more constant character of the mastoid than of the squamosal, and the argument becomes cumulative in favour of the mastoid or petromastoid character of no. 8 in the bird. When we remove the squamosal in the sheep we bring away the mandible which articulates with it, but we leave the distinct and independent tympanic closely articulated to the petromastoid. Precisely the same thing happens in the rodentia, in the marsupialia, and especially in the echidna, in which the tympanic has the slightest connection with the squamosal. The articulation of the tympanic therefore with the petromastoid is a more constant character than its articulation with the squamosal; therefore the articulation of the unquestioned tympanic bone in birds with the bone no. 8 is a

* The same formation of the upper boundary of the meatus externus is shown by Geoffroy in the young fowl.—Annales du Muséum, x. pl. 27. fig. 2. V. Q.

stronger proof of no. 8 being the petromastoid than of its being the squamosal: and for the same reasons that the articulation of no. 8 with the exoccipital, and its coalescence with the petrosal, are more essential characters of the petromastoid than they are of the squamosal, so I regard the articular surface furnished by no. 8 to the tympanic bone to be homologous with the articular surface of the petromastoid for the tympanic in the ruminants, rodents and other mammals, and am compelled to dissent from Dr. Hallmann's idea of its answering to the articular surface furnished by the squamosal to the mandible in mammals. In the ostrich a part of the articular cavity for the tympanic is excavated in the exoccipital, and would afford as good an argument to prove that bone to be the squamosal as the one which Dr. Hallmann has deduced from the same character in favour of the petromastoid in the bird being the squamosal. Dr. Hallmann cites the junction of no. 8 (his *t*, taf. i. fig. *5*, *op. cit.*) with the post-frontal in a young cassowary as evidence of its squamous character. I have not met with this union in the young ostrich nor in the young emeu, in which latter bird there is a distinct post-frontal: the anterior inferior angle of the parietal descends and meets the alisphenoid in both these *Struthionidæ*, at the part where the post-frontal is marked (at *f''*) in Dr. Hallmann's figure above cited. The extremity of the mastoid process does, however, arch over the temporal fossa to join the post-frontal process in certain birds, as above mentioned; but this junction, when we ascend in our pursuit of the homologies of the elements of the composite temporal bone of mammals, as it is safest to do, from fishes to reptiles, and from these to birds, forms a repetition of a very characteristic feature of the mastoid in the cold-blooded classes, and one that is quite intelligible when we rise to the appreciation of the higher relations of both mastoid and post-frontal as parapophyses of their respective vertebræ.

In every mammal the squamosal is applied to the cranial parietes, and attached by a peculiar suture called squamous; the outer surface of the bone exceeding the inner surface. In no bird is the mastoid so united to the surrounding bones, but joins them by harmoniæ vertical to the surface, as the other true cranial bones are joined before they coalesce; and the outer very little, if at all, surpasses the inner surface, to which the petrosal is confluent. The petromastoid of the mammal resembles that of the bird in this respect.

There is no difficulty in the ascensive survey in appreciating the special homology of no. 8 in the bird (fig. 23) with no. 8 in the crocodile (fig. 22) and in the fish (fig. 5); and Dr. Hallmann, retaining a firmer and more consistent view of their common characters than Cuvier, enunciates clearly this homology: but having persuaded himself that the 'mastoid' of the bird was its 'squamosal,' he concludes that the bone which Cuvier had called mastoid in the crocodile and fish must also be their squamosal. I believe Cuvier to have rightly determined the bone (no. 8) in the cold-blooded classes to be the mastoid; but he is not consistent with himself when he adopts a different conclusion with regard to no. 8 in the bird. The greater development of the bird's brain, as compared with the crocodile's, requires a greater expansion of the cranial part of the mastoid, just as the still greater development of the brain in mammals calls forth a peculiar expansion and application of the cranial end of the squamosal, involving a transference of the mandibular joint to that expanded end.

Cuvier, in descending from mammals to the consideration of the homologies of no. 8 in the bird, passed too abruptly to the comparison, lacking the instructive link furnished by the monotremes. It might have sufficed for the present report to have demonstrated the homology of no. 8 in the bird, ascensively, with Cuvier's well-determined mastoids in fishes and reptiles;

but since both Cuvier and Dr. Hallmann have elucidated their views of its homology by characters drawn from the mammalian class, I have endeavoured, and I trust satisfactorily, to meet their objections and to determine the true homology of the bone by other arguments drawn from modifications of the petromastoid in the same class.

Pursuing therefore the comparison descensively, I proceed in the next place to consider the characters of the mastoid in the crocodile (figs. 19 and 22, s). Cuvier premises his determination of the bone in that reptile by citing the following as its characters in the mammalia :—"La partie mastoïdienne qui recouvre le rocher en arrière de l'écailleuse et de la caisse, mais qui se soude de si bonne heure à ce rocher que l'on paroient à peine à la reconnaître comme distincte dans les plus jeunes fétus où elle est quelquefois double*." The squamosal he defines as a bone "qui devient de plus en plus étrangère au crâne à mesure qu'on descend dans l'échelle des quadrupèdes, en sorte que dans les ruminans elle est plutôt collée dessus qu'elle n'entre dans la composition de ses parois†." If we pause to apply these characters to the determination of nos. 8 and 27 respectively in the bird, before proceeding to the crocodile, we shall see how far they sustain the conclusions I have arrived at, in opposition to the views of Cuvier and his followers, in reference to the true homologue of the mammalian squamosal in birds. With regard to the mastoid in the crocodile, Cuvier says, "Le mastoïdien des crocodiles proprement dits et des gavials a cela de particulier, qu'il s'avance latéralement jusqu'à s'unir au frontal postérieur, et à entourer avec lui et le pariétal le trou de la face supérieure du crâne qui communique avec la fosse temporale; dans quelques caïmans il s'unit même à ces trois os pour couvrir entièrement cette fosse en dessus, et dans les tortues de mer, non-seulement ils font la même chose, le temporale et le jugal venant aussi à s'unir au mastoïdien et au frontal postérieure, ils couvrent la fosse temporale, même par dehors."‡

Doubtless the German anatomists who dissent from Cuvier's determination of the bone s in the crocodile (fig. 22) have been influenced in some degree by the little conformity between the character above assigned to the mastoid in that reptile and the character Cuvier had previously assigned to the mastoid in mammalia. The confluence of the mastoid with the petrosal, for example, is a modification peculiar to the warm-blooded vertebrates, whilst the relative position of the mastoid, above and external to the petrosal and behind the squamosal and tympanic, is a constant character in all vertebrates; to which must be added, that in most mammals and all other vertebrates the mastoid affords an articular surface for the tympanic bone, and developes an outstanding (mastoid) process for the attachment of strong muscles moving the head upon the trunk.

With regard to the relative position of the mastoid process to the cranial walls, its origin ascends as the expansion of the parietal diminishes with the decreasing size of the cerebrum: in mammals, the process, when present, extends from the lower border of the postero-lateral wall of the cranium: in birds it projects from near the middle of that wall, and nearer the upper surface in the flat-headed *Dinornis*: in the crocodile it has ascended to a level with the upper surface of the cranium, and forms the posterior angle of that surface. The paroccipital presents a similar progressive ascent, but later in the series traced descensively; it does not gain the level of the mastoid until we arrive at the class of fishes.

The mastoid, thus determined in the crocodile, is recognized with ease and certainty in chelonia, lacertia and ophidia. It is a distinct bone in all

* *Op. cit.* t. v. pt. ii. p. 81. † *Ib.* p. 81. ‡ *Ib.* p. 84.

these reptiles, and preserves with singular constancy its normal relative position anterior to the exoccipital, superior to and supporting the tympanic, and anterior to the squamosal when this is present. In lizards the mastoid is much reduced in size: in serpents it attains a considerable length. In the python and most serpents it forms no part of the proper wall of the cranium, but overlaps the contiguous parts of the parietal, alisphenoid, supra-occipital, and exoccipital, projecting backwards beyond the latter. It is large in the serpentiform batrachia, but presents in *Cæcilia* (Cuvier, Règne Animal, 1817, pl. 6. figs. 1 & 2, *g*) its normal connections with the occipital (*f*), parietal (*e*), tympanic (*k*), and also with the post-frontal, which has coalesced or is connate with the frontal (at *d*, l. c.). Cuvier does not admit of this confluence in the cæcilia; and although he assigns the character 'point des frontaux postérieures' to the typical batrachia*, gives the name 'posterior frontal' with a note of doubt, indeed, to *g*, and assigns to the bone *k*, which suspends the mandible, the name of "mastoïdiens et caisses réunis†." There is no actual necessity for assuming so rare a confluence to characterize the cæcilia. The mastoid exists with all its normal connections, and beautifully manifests by its independence and large size the affinity of the cæcilia to the true ophidia. In the typical batrachia, where the cranium is remarkably characterized by instances of confluence which seem borrowed from the warm-blooded classes, the mastoid sometimes loses its independence, and appears as an exogenous process from the external and posterior part of the parietal, retaining however its normal office of suspending the tympanic: but in a skull of the *Rana boans* now before me, the suture between the mastoid (fig. 13, 8) and parietal (7) is not obliterated, and it further articulates with the exoccipital (2) behind and the alisphenoid (6) in front. Cuvier, in his description of the tympanic of the *Rana esculenta*‡, says, that its upper branch articulates with the 'rocher.' In *Rana boans* that branch articulates exclusively with the truncated extremity of the broad outstanding mastoid, which mastoid overhangs, as in all fishes, the petrosal, which is chiefly cartilaginous in the *Rana boans* (*ib.* 10). In *Rana esculenta* the mastoid (Dugés, Recherches sur les Batrachiens, fig. 1, 12) appears to have coalesced with the alisphenoid (*ib.* figs. 2, 6 & 7, 12); and the compound bone has received the name of 'rocher' from Cuvier and that of 'rupéo-ptéreal' from Dugés. The foramen ovale however marks the alisphenoidal part (a distinct bone in my *Rana boans*), and the suspension of the tympanic marks the mastoid, which, with its other connections, overhangs also in *Rana viridis* that mass of cartilage§ which immediately invests the membranous labyrinth and forms the 'fenestra ovalis' against which the plate of the columelliform stapes is applied.

Prof. J. Muller has well recognized the homologue of this sense capsule in the *Cæcilia hypocyanea*, in which he describes it as "petrosum cum operculo fenestræ ovalis‖." It is situated further back than in *Rana*, and appears posterior to the tympanic (*i*) and the large suspending mastoid (*h*), to which Muller gives the name of 'temporale.' In the singularly modified cranium of the *Tythlops* the mastoid articulates above with the parietal and supraoccipital, behind with the exoccipital, coalesces in front with the alisphenoid, as in some batrachia, and affords the usual articulation below to the tympanic. How necessary it is to retain a clear and consistent appreciation of these evi-

* Ossem. Fossiles, v. pt. i. p. 386. † Règne Animal, ed. 1817, t. iv. p. 102.

‡ Ossem. Fossiles v. pt. ii. p. 390.

§ The precocious development of this capsule in the larva of the frog is well shown by Reichert, 'Entwickelungsgeschichte des Kopfes,' 4to, pl. i. figs. 13—15, *x*: it resembles that in the myxinoids and lampreys.

‖ Beiträge zur Anatomie der Amphibien; Tiedemann's Zeitschrift für Physiologie, Bd. iv. 1831, p. 218, pl. 18. fig. v. *k*.

dences of the homology of the mastoid is shown by the second synonym, 'os petrosum,' which it has received from the justly-celebrated author of this instructive memoir (pl. 20. figg. 10, 12, 13, 14, *p*). The actual capsule of the membranous labyrinth is covered by the mastoid and exoccipital, and remains wholly cartilaginous, as in other ophidia; and as it likewise does in *Rhinophis*, where its name 'petrosum' is in like manner transferred by Prof. Muller to the coalesced mastoid and alisphenoid. In *Cheirotes* the course of confluence proceeds to obliterate not only the suture between the mastoid and alisphenoid, but that between the mastoid and parietal; as also of those between the frontal, parietal and supra-occipital; the whole cranium presenting almost the extent of coalescence which characterizes the hot-blooded bird. Only the immediate covering of the membranous labyrinth remains cartilaginous.

The sides of the superior surface of the cranium of bony fishes usually extend outwards as a strong irregular ridge, from which three processes more particularly project, which are supported by three distinct bones, suturally united, and each impressed with an articular glenoid cavity. And here I cannot avoid remarking how beautifully the principle of vegetative repetition* is exemplified in the lowest class of the Vertebrata, where consequently the relations of serial homology of the parapophyses in question are unmistakeable. The posterior process or bone which sustains (in part) the scapular arch is the paroccipital (fig. 5, 4); the anterior one, which sustains in part the tympano-mandibular arch, is the post-frontal (*ib.* 12); and the intermediate and usually most prominent bone (*ib.* 8), which sustains in part the epitympanic (12*a*), and through that the hyoid arch, is the homologue of the bone whose essential characters have been discussed under the name of 'mastoid.' The paroccipital having now risen to a level with the mastoid, this forms the second strong transverse process at each side of the cranium. The process is developed from the outer margin of the mastoid; the inner side of the bone is expanded, and enters slightly into the formation of the walls of the cranial or rather the otocranial cavity, its inner, usually cartilaginous surface lodging the fibro-cartilaginous continuation of the petrosal which immediately covers the external semicircular canal. It is wedged into the interspace of the ex- and par-occipitals, the petrosal, the alisphenoid, the parietal and post-frontal bones. The projecting process lodges above the chief mucous canal of the head, and below affords attachment to the epitympanic or upper piece of the bony pedicle from which the mandibular, hyoid, and opercular bones are suspended: its extremity gives attachment to the strong tendon of the dorso-lateral muscles of the trunk.

It might have been supposed that this contribution to the walls of the cranial cavity, this articulation to the occipital and tympanic bones, all of which are constant characters of the mastoid in mammals, and but occasional ones in the squamosal—not to speak of the apophysial form and functions of the bone in question in the skull of fishes—would have made the balance incline to the choice of the 'mastoid' rather than of the 'squamosal' elements of the human temporal in the judgement of every unbiassed investigator of its homologies. The German anatomists, however, in falling with Cuvier into the mistake respecting the homology of the 'mastoid' (no. 8) in birds, with the squamosal in mammals, adhere more consistently to their error and continue to apply the name 'squamosal' or its equivalents to the homologous bone in reptiles (fig. 22, 8) and fishes (fig. 5, 8).

* This principle or law is explained in the first volume of my Hunterian Lectures 'On the Invertebrata,' in which classes of animals it is necessarily most strikingly and fully exemplified.

The high repute which M. Agassiz has so justly earned in ichthyotomy renders the accession of his name in support of Drs. Hallmann, Reichert, and Köstlin's determination of the bone in question, one to which those able homologists and their followers will naturally attach great weight, and which indeed has caused me to pause and retrace more than once, and with the utmost pains and care, every step in the series of comparisons which have finally brought conviction of the accuracy of the Cuvierian determination of no. 8 in fishes.

I am not aware that any anatomist has replied to the objections to the Cuvierian view propounded by M. Agassiz. Drs. Hallmann and Köstlin, who have published the most elaborate monographs on the temporal and other bones of the skull since the time of Cuvier, concur entirely with the learned Swiss naturalist. Dr. Reichert, in giving the name of 'squama temporalis' to no. 8, and that of 'processus temporalis posterior' to its process, transfers the name 'processus mastoideus' to the paroccipital (no. 4, fig. 5)*. It becomes then necessary to consider the arguments of M. Agassiz in favour of the homology of no. 8. in fishes with the squamosal no. 27 in mammals. In the valuable monograph on the osteology of the pike (*Esox*) in the 15th 'Livraison' of the 'Recherches sur les Poissons Fossiles,' the author says (p. 66), "Un os de la tête placé entre le frontal postérieur, le frontal principal, le pariétal, la grand aile sphénoïdale et l'occipital latéral, ne saurait jamais être envisagé comme correspondant à l'apophyse mastoïdienne du temporal. D'après ses liaisons, je crois donc qu'il faut envisager le *mastoïdien* de Cuvier comme l'analogue de l'*écaille du temporal* ou comme le *temporal* proprement dit. C'était déjà l'opinion de Spix, qui est tombé juste sur ce point." To this I reply that, in regard to the connections of the mastoid, those with the parietal, alisphenoid and exoccipital, are more constant than that with the frontal, which is interrupted in mammalia by the interposition of the expanded squamosal, peculiar to that class; but the mastoid retains its piscine connection with the postfrontal in many reptiles and some birds. On the other hand, the union of the squamosal with the frontal is by no means a constant character in mammalia: it is rarely found in the orang, still more rarely in man, never in the cetacea and monotremes, nor in certain ruminants, nor in the myrmecophaga, &c. The connection of the mastoid with the frontal is more common than is the connection of the squamosal with the exoccipital. It is a bold leap to take from the mammal to the fish in the determination of a variable bone like the squamosal: nevertheless, I would request the unbiassed reader to glance at fig. 12, whilst he reads M. Agassiz's *précis* of the character of the squamosal above cited, and see how far no. 8 deviates from it, save in regard to the frontal connection. Spix, who appears not to have traced the beautiful gradation of the mastoid in the mammalia, and who was unacquainted with the decisive step to its normal condition in the oviparous vertebrates made by the monotremes,—and who was influenced, therefore, by seeing that bone in higher mammals pushed back from any connection with the alisphenoid and postfrontal by the interposed squamosal, which usurps these connections and combines them with others, as with the parietal and tympanic, which the mastoid (no. 8) presents in fishes,—not unreasonably concluded that no. 8 represented the squamosal in that class; and it is probable that M. Agassiz, who received his anatomical rudiments at Munich, and was early engaged in describing the fishes collected in Brazil by the author of the 'Cephalogenesis,' might have derived a bias in favour of this view which prevented his assigning their due value to the connection of no. 8 in fishes with the paroccipital, and its contribution to the otocranial cavity.

* *Op. cit.* tab. iii. figs. 9 and 13, *p*, *q*.

In urging a reconsideration of the value and significancy of these characters, I may repeat that in mammals the mastoid constantly presents them, whilst the squamosal very rarely has the first, and not often the second character. It must also be remembered that the squamosal loses its connection with the frontal and progressively decreases in the mammalian class to less than the dimensions of the mastoid itself, as *e. g.* in echidna (fig. 12), whilst in this monotreme the mastoid, s, besides its connections with the parietal and exoccipital, extends forwards to articulate with the alisphenoid, s. If ossification were restricted in mammals to no. s, fig. 11, in reference to is, which remained cartilaginous, then no. s would have the same relation to the otocrane, or in other words, would contribute the same protection to the acoustic labyrinth, which no. s, fig. 5, performs in fishes; the external semicircular canal at least would be protected in the mastoid by both: only in mammalia the mastoid would also extend over the posterior canal. The petrosal loses no part of its essential character as the capsule or outer tunic of the labyrinth by becoming ossified, nor is it less recognisable in fishes within the mastoid, by remaining membranous or cartilaginous, than is the sclerotic capsule of the eye in its chamber or orbit; which capsule, in like manner, presents all the corresponding histological modifications in one or other part of the vertebrate series. The mask which has concealed the true features of resemblance in the human mastoid to that of fishes, is simply the petrosal ossified and cemented to it. But the squamosal presents no such relations to the bony capsule of the semicircular canals in any mammal. Even the connection of the squamosal with the tympanic bone is, as we have seen, far less constant and intimate in mammals than the connection of the mastoid with the tympanic*.

In the anatomical description of the existing ganoid fishes which M. Agassiz has unfortunately called 'Sauroid†,' the bone no. s is described as

* From the remark in p. 53, t. ii. pt. ii. 'Recherches sur les Poiss. Foss.,' it would seem that the circumstance of the extension of the tympanic air-cells into the mastoid, in certain mammalia, had weighed with M. Agassiz in determining its homological characters.

† All the characters by which these highly organized fishes approximate the *Reptilia* are found, not in the highest, but in the lowest order of that class, viz. in the batrachia, and herein more especially in the salamanders. The air-bladder of *Lepidosteus* resembles the lung of the serpent in its singleness, and those of the salamander in the degree of its cellularity; some parts of the structure being peculiarly piscine. The bifid air-bladder of *Polypterus* resembles the lungs of the salamandroid menopome and proteus, in the want of cellular walls. The characteristic large bulbus arteriosus and its numerous rows of valves, which distinguish the ganoids from most other osseous fishes, are retained in the menopome, but are not present in any saurian. The anterior ball and posterior cup of the vertebræ of *Lepidosteus* are repeated in the salamander and pipa, but in no existing saurian. The labyrinthodont character of the teeth of Lepidosteus was developed to its maximum in the great extinct reptiles (*Salamandroïdes*, Jäger), which, by their double occipital condyle, dentigerous double vomer, and biconcave vertebræ, were essentially *Batrachia*, not *Sauria*; and which combined characters now found in the lower salamandroid *Batrachia*, with the dental ones borrowed from fishes, and but feebly manifested by the most fish-like of saurians (*Ichthyosaurus*). All the so-called sauroid fishes retain the characteristic piscine articular concavity on the basioccipital for the atlas: it is, however, very shallow in the polypterus; and is also extended transversely, with the lateral borders or angles so prominent, that, as M. Agassiz well remarks, "it needs very little to change this transverse articulation with its two lateral ridges into two distinct articular condyles," *l. c.* p. 71. But this would convert, *pro tanto*, the polypterus into a batrachian, not into a saurian. So far as the character of a single convex occipital condyle is valuable as a mark of affinity to the *Sauria*, it is present in a fish of a different order from the ganoids, and with much fewer approximations in other respects to the reptilian class, viz. in the *Fistularia tabaccaria*. There remains, therefore, only the character of the enamelled scales which the polypterus and lepidosteus present in common with all the lower organized ganoids, and which to a certain extent resemble the bony scutes of the crocodilia. If the deposition of calcareous matter in and upon the skin were not essentially a retention of a very low type of skeleton; if it were not presented by

taking part, by its large size, in the formation of both the internal and external surfaces of the cranial* box, which size depends essentially on the degree of development of the frontals, parietals and occipitals: it is further urged that the suborbitals ('apophyse jugale') are likewise attached to it; that the preopercular ('apophyse styloïde') diverges, and is directed or abuts against it; that, finally, the bone in question (no. 8, fig. 5) is, with the exception of the petrosal, the sole part of the temporal bone which takes a direct part in the formation of the cranial box. "D'après ces considérations," M. Agassiz proceeds, "il est impossible de prendre l'os No. 12 [no. 8, in fig. 5], que Cuvier a nommé *mastoïdien*, pour autre chose que pour la véritable écaille du temporal. Il prend part à la formation de la boîte cérébrale, il donne insertion à l'arcade zygomatique, enfin, il prête une articulation au préopercule, que nous regardons maintenant comme le véritable représentant de l'apophyse styloïde du temporal," *l. c.* p. 63. Admitting, for the sake of the argument, that the preopercular is the homologue of the stylohyal, and that it articulates with the so-called 'écaille du temporal,' which is not the case in the majority of fishes, yet this would prove more for the 'mastoid' than for the 'squamosal' character of no. 8, fig. 5. The stylohyal unquestionably articulates in many mammals with the mastoid or petromastoid, between which and the tympanic it is anchylosed in man, and it rests with M. Agassiz to demonstrate the species in which it articulates with the true squamous part of the temporal†.

With regard to the connection with the suborbital chain of ossicles, which M. Agassiz regards, with Geoffroy, as the jugal or zygomatic arch, even admitting such connection to be the rule and not the exception, all its force as an argument in favour of the squamosal character of no. 8 will depend on the ultimate decision of comparative anatomists as to the respective claims of the upper and lower zygomata in the macaw's skull, for example, to a special homology with the zygomatic arch in man and other mammals. The orbit in the bird cited, as in other *Psittacidæ*, is circumscribed below by a bony frame continued from the lacrymal to the postfrontal, and thence to the bone (no. 8) which I regard as the mastoid. Below this frame, the slender bone, considered by Cuvier as the jugal, and by me as the coalesced jugal (28) and squamosal (27, fig. 23), extends from the maxillary (21) backwards to the tympanic (28), and forms a second arch or zygoma. According to the Cuvierian and generally-received view of the homology of no. 8 in the bird, the bridge which it sends forward over the temporal fossa to join the above-described inferior boundary of the orbit, in the macaw, would be the zygomatic process; and that boundary would be what M. Agassiz calls its homologue in fishes, viz. the jugal or 'arcade zygomatique.' But what then is the parallel zygomatic arch below, connecting

many fishes of different grades of organization, and by some, as the sturgeons and siluroids, *e. g.* under a scattered arrangement, more like that in the crocodiles than is seen in the scale armour of the typical ganoids, it might have some weight in proving the affinity of such ganoids to the highest order of reptilia; but, viewing this character under all its relations, I am not disposed to regard it as establishing that affinity more directly, than it would the affinity of the crocodile to the mammalian genus *Dasypus*. It is for the reasons above assigned that I have been accustomed to treat, in my Lectures, of the anatomical characters of the group represented by the *Polypterus* and *Lepidosteus*, as those of a *Salamandroid*, rather than of a *Sauroid* family of fishes; the characters being carried out in the direction of the batrachian order by the remarkable genera *Protopterus* and *Lepidosiren*.

* More properly 'otocranial,' in lepidosteus at least.

† In my notes on the osteology of Mammalia, I find that the stylohyal sometimes articulates with the petrosal, sometimes with the mastoid, exclusively, as in most mammals, sometimes with the tympanic, sometimes with the paroccipital process: but no instance is recorded of its articulation with the squamous portion of the temporal.

the maxillary with the tympanic, and marked $z^{m'}$ in fig. 7, taf. i. of Dr. Hallmann's monograph? If Cuvier had been correct in regarding no. 8 as the squamosal, the name 'jugal' ought to have been transferred from the lower zygoma to the upper one connected with such squamosal in the macaw: and with a like consistency the name 'jugal' ought to have been retained for the suborbital chain of dermal bones in fishes, to which it had been applied by Geoffroy St. Hilaire, and to which it has been restored by M. Agassiz. But, in truth, there may be clearly discerned in the beautiful modification which has been adduced from the *Psittacidæ*, a proof of Cuvier's erroneous homology of the bone no. 8 in the class of birds, and at the same time of his accurate homology of the same bone in that of fishes.

Is there no significance in the fact of the bone anterior to the orbit, which we call lacrymal in man down to the lowest reptile, being constantly perforated by a mucous duct? Can we not recognize in this function and glandular relation, as in the commonly thin scale-like character of that bone, and its connections in front of the orbit, the repetition of the characters of the largest, most anterior, and most constant of the suborbitals in fishes? If the rest of that chain be sometimes wanting, but more commonly present in that class; if it should present the condition occasionally of a strong continuous bony inverted arch, spanning the orbit below from prefrontal to post-frontal, as in the right orbit of the *Hippoglossus* and the left orbit of *Rhombus*; ought we to lose our grasp of the guiding thread of 'connections' by being confronted with a repetition of that condition in the skulls of certain birds, caused by a continuous ossification from the lacrymal to the post-frontal, seeing that a diverging bony appendage of the maxillary arch, unknown in the class of fishes, has there established a second and true 'zygoma' below the suborbital one? The extension of the ossification from the post-frontal crus of the suborbital arch to the mastoid is, in truth, a beautiful repetition of an ichthyic cranial character, not unknown however in the reptilia; and whilst it adds a proof of the mastoidal character of no. 8 in the bird, it reflects reciprocal confirmation of the accuracy of Cuvier's determination of that bone in fishes.

The true signification and homologies of the bones in that interesting class could never have been elicited from an exclusive study of it, however extensive, detailed or profound; nor will the feeble rays reflected from anthropotomical reminiscences lend sufficient light in their determination: they can be clearly discerned only by the full illumination of the beams concentrated from all the grades of organic structure. M. Agassiz, descending to the determination of the squamosal in fishes from its characters in man, concludes that it must be the bone no. 8, fig. 5, because that bone takes part in the formation of the inner as well as the outer walls of the cranial cavity. But this protective function is an exceptional one in the squamosal (fig. 6, 27); it is peculiar to that bone only in one class, and, as we have seen, is not constant even there; whilst, on the other hand, the mastoid is recognizable from the inner surface of the cranial walls of the highest mammal (in the human cranium where it is impressed with the fossa sigmoidea, fig. 6, 8), and in a still greater degree in that of the lowest mammal (*Echidna*, fig. 12, 8); whilst in almost every mammal, by its coalescence with the outer surface of the petrosal, it closely repeats the protective character in relation to the external semicircular canal, which it presents in fishes,—a function which is altogether foreign to the squamosal in every mammal. I have dwelt thus long, perhaps tediously, and it may be thought unnecessarily, on the true characters and homologies of the petrosal and mastoid. But their determination is essential to, and, indeed, involves that of the squamosal and other

dismemberments of the human temporal bone; and we cannot climb to the higher generalizations of anatomical science, except by the firm steps of true and assured special homologies. There are more important subjects than homologies, no doubt; but nothing is more important than truth, in whatever path we may be in pursuit of her.

Orbitosphenoid.—As evidence will be given in the section on 'General Homology' that both squamosal and tympanic belong to a quite distinct category of bones from the parts of the 'temporal' which have just been discussed. I shall proceed next to the neurapophyses that precede the alisphenoid.

As the determination of this bone (6 in all the figures) involves that of the orbitosphenoid (10), which has rarely been mistaken* for any other bone than 6, there remains little to be added in proof of its homology after what has been advanced respecting the alisphenoid. The most constant character of the orbitosphenoid is its relation to the optic nerve, which either perforates or notches it, whenever the ossification of the primitive cartilage or membrane holding the place of the bone is sufficiently advanced, which is not always the case in fishes, especially those with broad and depressed heads, and still more rarely in lacertine saurians. The recognition of the orbitosphenoid is also often obscured by another cause, viz. the tendency in the class *Reptilia*, and especially in ophidians and chelonians, to an extension of ossification downwards into the primitive membranous or cartilaginous neurapophysial walls of the brain-case, directly from the parietal and frontal bones.

In the fishes with ordinary-shaped, or with high and compressed heads, the orbitosphenoids are usually well-developed: they are, however, represented by descending plates of the frontal in the garpike; and they are, like the alisphenoids, mere processes of the basisphenoid in the polypterus, which thus offers so unexpected a repetition of the human character of the corresponding parts†. In the cod (fig. 5, 10) they are semielliptic, raised above the presphenoid (9), suspended, as it were, between the alisphenoid (6) and the frontal (11), and bounding the sides of the interorbital outlet of the cranium: the optic nerves pierce the unossified cartilage closing that aperture, immediately beneath the bone itself. In the malacopterous fishes with higher and more compressed heads, the orbitosphenoids are more developed; they are directly pierced or deeply grooved by the optic nerves, and are pierced also by the 'nervi pathetici' in the carp. The crura of the olfactory ganglions (rhinencephala) pass out of the interorbital aperture of the cranium by the upper interspace of the orbitosphenoid, into the continuation of the cranial cavity which grooves the under surface of the frontal, in their course between the orbits to the prefrontals. The orbitosphenoids protect, more or less, the sides of the prosencephalon; and this function, their transmission of the optic nerves, their anterior position to the alisphenoids, and their articulation above with the frontals, establish their special homology from the fish up to man.

In certain fishes a distinct centre of ossification is set up in the median line of the fibrous membrane or cartilage, closing the interorbital aperture of the cranium, below the orbitosphenoids, and extending forwards as the interorbital septum. The bone (represented in outline in fig. 5, at 9') extends downwards to rest upon the presphenoid (*ib.* 9), and bifurcates, as it ascends,

* Geoffroy in his memoir on the skull of birds (Ann. du Mus. x.), indicates the orbitosphenoid at P, fig. 2, pl. 27, as the 'rocher': and Cuvier describes it as part of his 'os en ceinture' in anourous batrachia.

† Agassiz, Recherches sur les Poissons Fossiles, ii. p. 38.

to join and prop up the elevated orbitosphenoids in the perch and carp (not in the cod). The relations of this ossicle are precisely those of the part forming the conjoined bases of the orbitosphenoids in mammals, and usually called the 'body of the anterior sphenoid,' in them; though this is developed from two distinct centres. In the young whale I found it supported by a direct extension of the basisphenoid forwards, which joins the backwardly prolonged vomer, as in fishes. The common base of the orbitosphenoids is peculiar, as a distinct bone, so far as I know, to fishes. It has been called by Bojanus* the 'basis alarum minorum sphenoidei seu rostrum sphenoidei'; by Geoffroy 'entosphénal'; and by Cuvier 'le sphénoïde antérieure.' M. Agassiz opposes these determinations by the following remarks, founded on the embryological researches of the ingenious Dr. Vogt:—"In fishes with a short and thick muzzle, the cartilaginous embryonal plate ('plaque faciale' of Vogt), which serves as the base of support to the prosencephalon and the nasal fossæ, is transformed into an independent bone, "se transforme intégrulement en os." It is then, he says, "represented by the cranial ethmoid (le *sphénoïde antérieure* of Cuvier), an azygous bone, 'os impair,' short, of an almost square form, in which are pierced the canals for the transmission of the olfactory nerves. But in the fishes with elongated muzzles, and of which the eyes in place of preserving their primitive lateral position at the sides of the mesencephalon are carried forwards in advance of the cranium between that and the nasal fossæ, the relations of the 'plaque faciale' are necessarily altered: part of the plate remaining in its primitive situation is transformed into the 'cranial ethmoid,' the other part is carried forwards, but is never transformed into a distinct bone: it remains cartilaginous as the nucleus of the muzzle; or if, indeed, the ossification of the muzzle is completed, it disappears by virtue of the progressive encroachment of the exterior ossification. This is the reason why fishes have never a true 'nasal ethmoid' (the bones called ethmoid by Cuvier are the nasals), but only a cranial ethmoid†." Influenced by the deservedly high authority of M. Agassiz, I adopted his homology of the bone *s'* in the 'Hunterian Lectures on Vertebrata,' delivered in 1844. But since the notes of those lectures were printed, having been charged with the formation of a new Osteological Catalogue of the Hunterian Museum, I have carefully reconsidered this question. Passing over, for the present, the assertion that the homologue of the 'nasal ethmoïde' does not exist in fishes, I would first observe, that if the orbital aperture (or what appears to those who deem the rhinencephalic crura to be olfactory nerves, the anterior aperture) of the cranium were homologous with the aperture closed by the cribriform plate in man, then any bony bar or plate tending to close that aperture might be held to be homologous with the cribriform plate or crista galli of the ethmoid: but the interorbital aperture of the cranium is always bounded laterally, in fishes, by the orbitosphenoid; and the rhinencephala and their crura extend forwards, to a considerable distance in most fishes, before the olfactory nerves sent off from the rhinencephala escape by those perforations in the prefrontals, which are the true homologues of the single foramina of the olfactory nerves in the so-called ethmoid of birds, and of the cribriform foramina in mammals. The interorbital groove or canal in the skull of fishes, which is continued from the presphenoidal or interorbital aperture to the prefrontal foramina, is as essentially a part of the cranial cavity as is that contracted anterior olfactory chamber of the cranium of mammals, which, in the thylacine, for example, extends forwards, from where the orbitosphenoids sustain the frontals, ex-

* Oken's Isis, 1818, p. 508.

† Recherches sur les Poissons Fossiles, t. i. p. 120.

panding, to where the frontals and the modified prefrontals (ethmoid) form the actual anterior boundary wall of the cranial cavity; the chief distinction between the condition of this boundary in the mammal and the fish, being, that whereas it is perforated by numerous apertures in the mammal, the olfactory nerves in the fish escape each by a single foramen or groove in the homologous bones. As beautiful as true was that clear perception by Bojanus of the homology of the simply perforated prefrontal of the fish, with its sieve-like homologue in the class in which the olfactory sense reaches its maximum of development and activity, and modifies all around it. The coalesced bases of the orbitosphenoids, forming the anterior boundary of the bed of the optic chiasma, answer to the separate ossification called 'ethmoïde crânien' by Agassiz, in fishes: it has the same relation with that contracted area of the cranium answering to the interorbital aperture of the cranium in fishes, which the so-called cranial ethmoid (entosphenoid) presents in fishes; and this same entosphenoid (fig. 5, 9') has as little relation to the formation of the canals pierced by the olfactory nerves in fishes, as the orbitosphenoid has in mammals. The olfactory, rhinencephalic or anterior division of the cranial cavity in most fishes has its lateral bony walls incomplete, and it opens freely, in the dry skull, into the large orbital chambers below, which are then said to have no septum: we see a similar want of definition of the cranial cavity in relation to the great acoustic chambers in most fishes. But in mammals the orbits are always excluded from the rhinencephalic, or olfactory compartment of the cranium*; and a like exclusion obtains in some of the highly organized ganoid fishes and in the plagiostomes. As the prosencephalic parts of the brain progressively predominate, and the rhinencephalic parts diminish, in the higher mammals, the compartment of the cranium appropriated to the latter loses its individuality, and becomes more and more blended with the general cavity. In the elaborate 'Iconography of Human Anatomy' by Jules Cloquet, for example†, the small peculiarities of the 'trou borgne' and the 'apophyse crista galli' are both indicated, and very properly; but the rhinencephalic or olfactory division of the cranial cavity, though defined by the suture between the orbitosphenoids and prefrontals and lodging the olfactory ganglia or rhinencephala,—so important an evidence of the unity of organization manifested in man's frame and traceable in characters, strengthening as we descend to the lowest osseous fishes—is wholly unnoticed. Thus, very minute scrutiny, conducted with great acuteness of perception of individual features, qualities highly characteristic of the anthropotomists of the school of Cloquet, being directed from an insulated point of view, prove inadequate to the appreciation of sometimes the most constant and important features of their exclusive subject.

But to return to the homology of the orbitosphenoids. In the menopome these neurapophyses are elongated parallelograms, perforated by the optic nerves, and are distinct bones. In the great bull-frog (*Rana boans*) they present a similar form (fig. 13, 10), but are confluent with the prefrontals (14): in both batrachians an unossified space intervenes between them and the ali-

Fig. 13.

Side view of cranium (*Rana boans*), nat. size.

* This is not to be confounded with the olfactory chamber itself, lodging the organ of smell.

† Manuel d'Anatomie Déscriptive, 4to, Atlas, pl. 8, fig. 2.

sphenoid (*o*). In most lizards the wider roof of the cranium, supported by the long mastoids, squamosals, postfrontals and malars, like a bony scaffolding on each side, is independent of its proper (neurapophysial) walls for support, and these retain, through the œconomy of nature, their primitive semi-membranous, semi-cartilaginous state. A dismemberment of the alisphenoid (which may be discerned as a process of that bone in the piscine genera *Xiphias*, *Sphyræna*) props up the parietal upon the pterygoid, so like a post or pillar, that the name 'columella' may well be retained for it. At the sides of the membrane forming the orbital aperture, rudiments of the orbitosphenoids may be seen in most lacertia: I find them, *e. g.* in the form of a slender osseous filament on each side, slightly bent inwards and bifurcate above, in a large Australian lizard (*Cyclodus gigas*). In the crocodile (figs. 9, 20, and 22, 10) the orbitosphenoids attain their maximum of development, but retain all their typical characters: they bound the orbital aperture of the cranium; are notched below, as in many fishes, by the optic nerves (*op*); are perforated by the pathetic and other orbital nerves at the 'foramen sphenoorbitale' (*s*); they protect the sides of the prosencephalon; support above the frontals (and by their backward development also the parietals); and they rest below upon a peculiar development of the presphenoid (*9*), which seems to answer to the entosphenoid in fishes.

Some salient points of resemblance between the cranial organization of fishes and birds have elicited remarks from more than one comparative anatomist. Not to dwell upon the more obvious correspondence arising out of the mobility of the upper jaw, chiefly through its connection with the pedicle of the lower jaw, I may indicate the overhanging position of the orbitosphenoid (figs. 8, 23, 10), raised high above the presphenoid (*9*), at the back part of the interorbital septum: we see exactly the same position of the orbitosphenoid in many fishes. Cuvier accurately represents it in the skull of the perch*. This beautiful trait of unity of organization is completely put out of sight by the false homology of the orbitosphenoid in fishes with the alisphenoid in birds and mammals. The progressive recession of the orbitosphenoid and alisphenoid, as we descend from mammals to fishes, transfers indeed their characteristic nerve-notches or foramina from their posterior to their anterior margins. But the notch (*op*, fig. 8) at the posterior margin of the orbitosphenoid in the bird for the escape of the optic nerve by a foramen common to it and the nerves of the orbit, is not less significant of its true homology than is the anterior notch in the crocodile or fish; the osseous connections with the sphenoid below, with the frontal above, and with the alisphenoid behind, being the same.

Prefrontals.—If the cranium of a cod-fish be bisected horizontally and longitudinally, its most contracted part will be found at the upper part of the interorbital aperture, bounded by the orbitosphenoids, which mark the division between the prosencephalic and rhinencephalic compartments of the cavity: the latter extends as a triangular channel or groove on the under part of the frontal, opening below into the orbits, gradually expanding as it advances forwards, and dividing into two canals, which diverge to the interspaces left on each side of the nasal, between it and the bones (fig. 4, 14), that, meeting behind the anterior expanded end of the nasal, bound the anterior extremity of the true and entire cranium. The diverging canals of the rhinencephalic compartment are formed by the two bones in question: the rhinencephala or olfactory ganglions are sometimes lodged at the extremities of these canals, and they send out the olfactory nerves by the apertures formed between the bones 14 and 15, which then ramify upon the vascular olfactory sacs,

* Histoire des Poissons, pl. ii. figg. i. vii. 14.

supported by the bones 19, fig. 5. For the arguments by which the olfactory ganglions in the cod are shown to be homologous with the olfactory ganglions that rest upon the cribriform plate in man, and by which the medullary cords or crura connecting them to the rest of the brain are shown to be homologous with the so-called 'olfactory nerves' in the human cranium, and for the general homology of both as primary divisions and peduncles of the encephalon, the reader is referred to Dr. Desmoulins, 'Anatomie des Systèmes nerveux des Animaux à Vertèbres,' 1825, 8vo. t. i. p. 169; to Mr. Solly's excellent treatise 'On the Human Brain,' 1836, p. 78; and to my 'Lectures on the Vertebrata,' 1836, p. 184. I there adopt the expressive name applied by MM. Vogt and Agassiz to this most anterior of the four primary divisions of the brain of fishes, and apply to the peduncles of the 'rhinencephala,' which are frequently of great length in fishes, the name of 'rhinencephalic crura,' since they are serially homologous with the prosencephalic or cerebral crura; and I call that division of the cranial cavity which specially lodges these crura and their lobes the 'rhinencephalic' chamber or compartment. The right appreciation of the above essential characters of the most anterior division of the brain and the brain-case is indispensable to the accurate pursuit of the homologies of the bones 12, 14 and 15, whose development, especially of the pair no. 14, is governed by that of the rhinencephalon. In man the all-predominating cerebrum, overarching the mesencephalon and epencephalon behind, and the rhinencephalon in front, so modifies the surrounding cranial bones as to obliterate every part of the rhinencephalic division, save the terminal fossa that immediately supports the so-called 'olfactory ganglia,' which fossa seems, as it were, to be unnaturally drawn in and blended with the great prosencephalic chamber, by reason of the enormous outswelling development of the proper spines or roof-bones of that chamber, the frontals. Still, even here, through the absence of any commissural band connecting together the rhinencephala, a fibro-membranous process of the endoskeleton extends between them, and into this septum ossification extends from below, called the 'crista galli.' In the cod-fish the homologous partition between the rhinencephala is cartilaginous, and it extends some way back between their crura, not being opposed by a coextended overhanging cerebrum with great transverse commissures. In many fishes (e. g. *Xiphias*) the outlet of the olfactory nerves, which notches the inner side of no. 14 in the cod, is converted into a foramen by the extension of ossification around the mesial surface of the nerves. Where the olfactory nerves are sent off from the ganglions in great numbers (e. g. *Raia*), they perforate a membrane before reaching and ramifying upon the vascular pituitary sac. In man, the homologous membrane, or basis of the olfactory capsules, is ossified, and called from its numerous apertures the cribriform plate. The holes which these cribriform plates fill up are homologous with the foramina, or grooves forming the outlets of the olfactory nerves in the bones no. 14 in fishes (figs. 4 and 5).

The grounds for this homology are so plain that we cannot be surprised that they should have been early appreciated, as *e. g.* by the painstaking and philosophic Bojanus in 1818*. I never could comprehend the precise meaning of the statement with which Cuvier opposed his view:—"M. Bojanus, partant sans doute du trou qu'il a dans plusieurs poissons pour le nerf olfactif, en fait une lame cribleuse de l'ethmoïde; mais cette opinion, qui n'a pas ce soutien dans toutes les especes, est réfutée d'ailleurs par les autres rapports de cet os avec les os voisins†." Cuvier seems to have thought the ground of Bojanus's opinion to be cut away by the fact that in the cod and some other fishes the

* Isis, heft iii. p. 503.

† Histoire des Poissons, i. p. 235.

olfactory nerves groove instead of perforate the bones no. 14. But the trigeminal still determines the alisphenoid, whether it perforates or notches that neurapophysis in its escape: the relation of the alisphenoid to the division of the 5th, including the gustatory nerve, and that of the orbitosphenoid to the nerve of sight, are not more constant than is the relation of no. 14 to the nerve of smell. The differences of connection of no. 14—'les autres rapports'—are not specified by Cuvier, and I know none that affect its essential character.

No. 14 is however the most anterior of the neurapophysial or lateral bones of the true cranium, and is in relation with the anterior terminal division of the encephalon and with the first or anterior terminal pair of nerves. Like all extreme or peripheral parts, it is subject, as we should be prepared to find it, to a greater extent and variety of modifications than the more central neurapophyses. The difference between its connections in the fish and that of the cribriform plates and their sustaining basis in man may therefore be expected to reach the extremes of possible homology. It will be interesting to inquire whether there are intermediate modifications by which the nature of that difference may be appreciated, and how many of such links are permanently retained in the intervening species.

We might anticipate the smallest amount of departure from the fundamental vertebrate type, as respects form, size and connections of the bones in question, in that class where the principle of vegetative repetition most prevails and the archetypal plan is least obscured by teleological adaptations. Adopting the name modified from the phrase applied to these bones by Cuvier in those vertebrata in which they present their most typical characters, we find the 'prefrontals' in all bony fishes resting below upon the vomer (figs. 4 and 5, 13) and on part of the presphenoid (9), sustaining by their mesial and upper surfaces the nasal (15) and fore-part of the frontal (11), affording the whole or part of the surface of articulation for the palatine (20) or the palato-maxillary arch, and giving attachment exteriorly to the large suborbital or lacrymal bone (figs. 22 and 25, 72), when this exists. Besides their protective functions, in relation to the olfactory ganglions and nerves, they close the cranial cavity and bound the orbits anteriorly. The most constant and characteristic connections appear to be with the vomer, nasal, palatine and frontal. In the muræenoid fishes, where confluence begins to prevail in the cranial bones, we find that the prefrontals coalesce with the vomer and nasal, not with the true frontal. This fact, though not of a class materially affecting relations of homology, is not devoid of significancy in regard to the real character of the bone usually described as one of the 'deux démembremens du frontal*.' A clew not to be neglected in tracing the homologies of the prefrontals is their histological progress, although the value of such embryonic characters has been overrated and their application sometimes abused. The substramen of their ossification, like that of the exoccipitals, mastoids and post-frontals, is a cartilaginous mass, a part of that which M. Dugés has called 'cartilage cranio-faciale,' and M. Vogt 'plaques protectrices latérales.' The frontals and parietals, being ossified in supra-cranial fibrous membrane with so rapid and transitory a cartilaginous change as to have escaped general recognition, have been, on that account, rejected from the vertebral or endo-skeletal system of bones by Dr. Reichert, and with as little real ground as the rejection of the vomer and sphenoid from the same system, because they are ossified in membrane extended from the under and fore-part of the sheath of an evanescent subcranial 'chorda dorsalis,' like the homologous basal ossification beneath the coalesced anterior abdominal vertebra of the siluroids.

* Agassiz, *op. cit.* i. p. 123.

M. Dugés, who has accurately figured the 'cranio-facial' cartilage of a gadoid fish in pl. ii. of his valuable Monograph *, gives as accurate a figure of the same cartilage in the *Rana viridis* (pl. i. figs. 6, 7, of the same work), out of which has been ossified a bone which transmits the olfactory nerve to its sense-capsule: this bone (15 in the figures cited) rests below upon the divided vomer and on the end of the presphenoid, sustains above the nasal and fore-part of the frontal, affords an articular surface on its outer part for the palatine, and only fails to repeat every characteristic connection of the prefrontals in fishes, because (as likewise happens in certain of that class) there is no lachrymal bone developed in the *Batrachia*. The sole modification of any consequence tending to mask the homology is this; that whereas we find in many fishes ossification extending into the persistent part of the craniofacial cartilage connecting, whilst it separates, the prefrontals, so as to circumscribe the canals for the transmission of the olfactory nerves, such ossification proceeds in the anourous batrachia to anchylose the prefrontals with each other, and convert them into a single bone. This difference however sufficed with Cuvier to make of it a new and peculiar bone—an 'os en ceinture†.' It would have been as reasonable to have given a new name to the supraoccipital in the *Lepidosteus*, because it is divided in the middle line instead of being single, or to the frontal in the species where it is single instead of being divided, or to the vomer in the frog because it is double instead of single, or to the exoccipitals in the same reptile, which manifest the same mesial and annular confluence as the prefrontals. But, adds Cuvier, in reference to the single bone (fig. 13, 14) resulting from this modification, "Je ne l'ai pas trouvé divisé, même dans des individus très-jeunes qui avoient encore un grand espace membraneux entre les os du dessus du crâne." Nor did the great anatomist ever find the rudiments of the radius and ulna distinct at any period of development of the single bone of the *Batrachia*, which he nevertheless rightly describes as representing both bones of the fore-arm: nor did he ever find a division of the single parietal in the embryo crocodile, which he equally well recognized, nevertheless, as the homologue of the two parietals, which in most fishes have been subject to greater modifications in their connections and relative position than the single prefrontal presents in the anourous batrachia. These are not the only instances where relations of homology are by no means obscured, nor ought to be, by reason of the confluence or even connation‡ of essentially distinct elements. The capsule of the olfactory organ, partly protected by the anterior infundibular expansions of the connate prefrontals, undergoes no partial ossification homologous with the 'turbinal' (19, fig. 5) of fishes, but remains cartilaginous, like the sclerotal and petrosal.

The prefrontals, however, are not only connate with each other in the frog, but coalesce with the contiguous neurapophyses—the orbitosphenoids (16, fig. 13). And this modification has led Cuvier, notwithstanding the connection of the bone 16 with the presphenoid below, with the frontal above, and with the prosencephalon, optic nerve (*op*) and orbit, to characterise the batrachian skull as having "un seul sphénoïde sans ailes temporales ni orbitaires;" the true and distinct 'alisphenoid' (6, fig. 13), with its typical connections and nerve-perforations (*tr*), being described as the pe-

* Recherches sur l'Ostéologie, &c. des Batraciens, 4to, 1835.

† Ossemens Fossiles, 4to, t. v. pt. ii. p. 387. He had before applied the name of 'ceinture osseuse' to the scapular arch in fishes.—Leçons d' Anat. Comp. i. (1800) p. 332.

‡ I use these terms in the same definite sense as the botanists; those essentially distinct parts are *connate* which are not physically distinct at any stage of development, those united parts are *confluent* which were originally distinct.

trosal, 'rocher*.' But the real difficulties which beset the quest of general truths in comparative osteology are such that we may well dispense with any over-statements of the amount of deviation from the cranial archetype which much-modified skulls like those of the anourous batrachia may present. Fortunately the light which the development of such skulls throws upon their mature characters, is aided by the persistent larval stages manifested by the perennibranchiate species.

In the menopome, for example, the prefrontals remain distinct, both from each other and from the orbitosphenoids†, their characteristic connections and functions being the same as those of their coalesced homologues in the frog, except that they are notched, instead of being perforated by the olfactory nerve, which grooves their inner border, as in the cod and some other fishes. Cuvier just hints at the possibility of his 'os en ceinture' in the frog representing "à la fois le frontal principal et l'ethmoïde‡," or as having an equal pretence to one or the other name.

The suture, however, which marks the limits between the frontal 11 and parietal 7 is persistent in the menopome, and indeed in all batrachians but the anourans; and even in the very young larvæ of these, Cuvier admits (and the observations of M. Dugés warrant the admission) "que l'on sépare une partie postérieure de forme ronde de l'antérieure qui est allongée" (*Ibid.* p. 387). The permanently distinct frontals present a similarly elongated form in the urodeles, and are therefore recognized by Cuvier in the salamander, *e. g.* at *c*, pl. xxv. fig. 1, *op. cit.*; in the newt, pl. xxvi. fig. 6; in the menopome, fig. 4; in the axolotl, pl. xxvii. fig. 24; in the siren, *ib.* fig. 2; and in the amphiuma, *ib.* fig. 6. In all these crania the true frontals are indicated by the same letter *c*; in none of them do they close the cranial cavity or bound the orbits anteriorly, or are perforated by the olfactory nerves, or articulate with the vomer below, or perform any of the essential functions, or combine the characteristic connections of the prefrontals of fishes, all of which concur in the 'os en ceinture.' But the frontals do present the chief connections and occupy the relative position of the anterior half of the bone (11—7, fig. 13) which Cuvier calls the parietal in the frog. The evident tendency to coalescence of essentially distinct bones which pervades the skeleton in the adult anourans greatly diminishes the difficulty, through the loss of the suture between the parietal and frontal, of recognizing the homology of the latter bone, which, with that exception, not only repeats the characters of the frontals in fishes, but of those in most tailed batrachians.

Next, then, with regard to the ethmoid, the second of the two bones to which Cuvier restricts the choice of the homologues of the 'os en ceinture,' no. 14. No name has been applied more vaguely or with a less definite meaning than this same 'ethmoïde.' In the sense in which Cuvier would permit its application in the present instance, it is a bone which forms the

* *Op. cit.* p. 386.

† The menopome, which represents a gigantic tadpole of the tailless batrachia, manifests a beautiful conformity to the general type, and well illustrates the real nature of the apparent deviations which take place in the course of the remarkable metamorphoses of the anourans. At first sight the orbitosphenoids seem to be barred out from their normal connection with the frontal by the junction of the parietal with the prefrontal in the menopome, as appears, for example, in the figure given by Cuvier in the 'Ossemens Fossiles,' v. pt. ii. pl. xxvi. fig. 4, where *c' h* divides *c* from *u*. Remove, however, the prefrontal *h* from the parietal *c'* (which may be readily done, the suture, which is not indicated in the figure cited, being persistent), and the anterior and mesial half of the orbitosphenoid (*u*) is then seen extending inwards (mesiad), beneath the parietal and prefrontal, to join a triangular surface formed by a descending process from the middle of the outer edge of the frontal.

‡ *Op. cit.* p. 388.

anterior and antero-lateral walls of the cranium, defends the rhinencephala and transmits the olfactory nerves, but is altogether distinct from and posterior to the capsules of the organs on which those nerves are ramified. In the crocodile Cuvier restricts the term ethmoid to the cartilaginous laminæ, capsules, or supports of the olfactory ramifications after the nerves have left the cranium. In mammals the ethmoid is made to include both the bones that close the cranium anteriorly, support the rhinencephala, give exit to the olfactory nerves, and those which defend and sustain the enormously developed and complex superior parts of the organ of smell*. Whilst this confusion is permitted to vitiate osteology, it is plain that no intelligible homological or other proposition can be predicated of the 'ethmoid.'

When Cuvier, with reference to the hypothetical possibility of the homologue of the frontal forming part of the bone 7—11 in the frog, adverts to the second chance of bringing the 'os en ceinture' into the ordinary category of cranial bones, by viewing it as the 'ethmoïde,' he adds, that it would then be "un ethmoïde ossifié, ce que sera une grande singularité" (*ib.* p. 388). Here it is obvious that the predominating idea of the ethmoid was that presented to his mind by the capsules of the olfactory organ in the crocodile and other reptiles, which he had so called, and which are wholly or in great part cartilaginous. But the parts of Cuvier's ethmoid in birds and mammals, which are in functional and physical relation with the cranial cavity, rhinencephala and olfactory nerves, are ossified: the bone, also, to which he gives the name 'ethmoid' in fishes (fig. 5, 15) is ossified; and, what is more to the purpose, the bones (14) in fishes, ophidians, chelonians and saurians, which repeat the essential characters of the batrachian 'os en ceinture,' are likewise ossified.

General homology teaches that the bone or bones in relation to the defence of the rhinencephala and the transmission of their nerves belong to one class, and that the parts of the skeleton, whether membranous, gristly or bony, which form the capsule or sustain the olfactory organ itself, belong to another and very different class of parts of the skeleton. But, not to anticipate what belongs more properly to a subsequent section of this report, observation shows the two parts to be physically distinct in all vertebrates except mammals, and to be distinct in the fœtus of these. Whether we restrict the term 'ethmoid' to the neurapophysis or to the sense-capsule (which in mammals constitutes the 'conchæ superiores' and cells of the ethmoid), the term must be applied arbitrarily in its extended or homological signification, since the neurapophysis dismisses the nerve by a single foramen or groove in all the vertebrates below mammals. The multiplied foramina in the neurapophysial or cranial part of the anthropotomical 'ethmoid,' whence that name, as well as the special designation of the part called 'lamina cribrosa,' are modifications peculiar to the mammalian class, but not constant here, and they form no essential homological character of the bone in question. It appears to me preferable, since we have two essentially distinct parts of the skeleton combined in the mammalian and human ethmoid, to restrict the term to the

* Objecting to Oken's idea, that the prefrontal in the crocodile was homologous with the part of the ethmoid called 'os planum' in anthropotomy, Cuvier says, "Or l'os planum ne paroît jamais sur la joue; il ne se montre plus dans l'orbite à compter des makis si ce n'est un petit point dans les galeopitheques et dans quelques chats. Dans tous les autres mammifères l'ethmoïde est entièrement enveloppé et caché par le palatin" (note that significant connection) "et par le frontal et spécialement par cette partie du frontal dont il est maintenant question et qui se détache dans les ovipares. Le véritable ethmoïde est enveloppé de la même manière dans le crocodile, quoique presque toutes ces parties restent cartilagineuses."—Ossem. Foss., v. pt. i. p. 73.

part which appertains to the sense-capsule, *i. e.* which is directly concerned in the support of the membrane and cells of the olfactory organ.

But leaving for the present the question of names, and returning to things, let us pursue our search and comparisons of the bones which continue in the higher classes to repeat the essential characters of those called 'prefrontals' in fishes. Were it necessary to add to the reasons above assigned for regarding no. 14, fig. 13, as the homologues of 14 in the fish, notwithstanding they are connate in the batrachian, I would cite the structure and relations of those bones in the sword-fish. The whole of the anterior part of the extensive interorbital space is occupied by the prefrontals, which join each other at the median line by an extensive vertical cellular surface: they form the anterior border of the orbit, and the posterior wall of the nasal fossa; they close the cranial cavity anteriorly, and transmit the olfactory nerve to the capsule by a central foramen. They are almost entirely covered by the frontals above, which they support by a broad flat surface; a very small portion only appearing on the upper surface of the skull at the anterior angle of the orbital ridge. Were the frontals separated, the prefrontals would then appear, as in the frog, at the median line: were the suture between the two prefrontals to be obliterated in *Xiphias*, an 'os en ceinture' would be produced like that of the frog. The nasal bone of the sword-fish, which Cuvier calls 'ethmoïde,' presents a cellular structure of its base, designed to break the force of the concussion arising from the blow which is delivered by the 'sword.' But the prefrontals manifest more extensively this peculiar cellular structure, which Cuvier well says, "l'on prendrait presque pour les cellules de l'ethmoïde d'un quadrupède*."

Cuvier, not perceiving or not appreciating the grounds of the homology of the 'os en ceinture' with the prefrontals, describes the divided nasal (15, fig. 13), in the batrachia as the 'frontaux antérieures'; and reciprocally, having called the bones in fishes, homologous with the bone 14, (which he thought might represent the ethmoid in the frog) 'frontaux antérieures,' he gives the name 'ethmoïde' to the bone 15, fig. 5, whether single or divided, in fishes. It is not necessary to add anything to the arguments by which M. Agassiz has sustained the conclusion of Spix, that Cuvier's 'ethmoid' in fishes is the 'nasal.' And it needs, I think, only to compare the connections of the bones 15, fig. 13, with either the single or the divided nasals in fishes, and to glance at the obvious homology of the bones *h* in Cuvier's pl. xxiv. fig. 1—6, with the bones *g g* in figs. 4 & 6 of pl. xxvi. ('Ossemens Fossiles,' t. v. pt. 2), to ensure the acceptance of the conclusion, that his 'frontaux antérieures' in the frog and the other anourans are the true nasal bones.

In the python Cuvier transfers the name 'frontaux antérieures' to the lacrymal bones. The bones in this serpent, which are in neurapophysial relation with the olfactory nerves, and which present other essential characters of the prefrontals (14) in fishes, are also two in number, in the form of thin osseous plates, intervening on each side, anterior to the frontal, between the vomerine and nasal bones, bent outwards in the form of a semicylinder about the olfactory nerves, which they support and guide to the cartilaginous capsule of the organ of smell, and having the palatine bones articulated to their under and outer sides. The bones, which thus present every essential character of the prefrontals, are those (*s s* in pl. ix. figs. 1, 2, 3, 'Règne Animal,' t. iii. 1830) which Cuvier there calls 'cornets inférieures.' But the true 'cornets' (turbinals) are cartilaginous in serpents as in every other reptile, and give attachment to the palatines in no animal. The bones *b b* in

* Hist. [illegible] viii. p. 194.

the same figures, to which the name of 'anterior frontal' is given, have no relation whatever to the protection of the rhinencephala or the exit of the olfactory nerves, but they have a large perforation for the passage of the muco-lacrymal duct from the eye. They repeat indeed the single and least essential character of the prefrontals, in standing anterior to the frontals and the orbits; but these are characters common to the great anterior mucous scale-bone in fishes, whose essential function—the transmission of a mucous duct—they superadd to the repetition of its connections, viz. with the prefrontal, nasal and superior maxillary bones*.

The bones, which more resemble the anchylosed prefrontals in the frog, are the frontals of the python; but the resemblance is confined to one character only, and that an exaggeration of a character common to the frontal bones of many birds, and of the ornithorhynchus among mammals, viz. a development of a median bony partition from the line of the frontal suture into the median interspace of the encephalon. In the python each frontal sends down at the fore-part of this suture such a partition, which is therefore double, as the falx essentially is in man and the mammalia, in which it retains its primitive histological condition of a fibrous membrane. The ossified laminæ of the falx in the python bend outwards and coalesce below with the external or orbitosphenoidal plates of the frontal, and thus surround the lateral divisions of the fore-part of the brain; in fact, the olfactory nerves, drawn back in the progress of the concentrative movement of the cerebral centres, so as also to occupy the prosencephalic segment of the cranium, the prosencephalon being, in like manner, protected chiefly by the mesencephalic bony arch. The change is precisely analogous to that which takes place at the opposite extremity of the neural axis in higher animals. In the python every segment of the spinal chord retains its primitive relation to the segment of the endoskeleton, through which it transmits its pair of nerves. In the mammal the concentrative movements of the spinal chord draw its segments in advance of their proper vertebræ, and the primary relation is indicated by the nerves which these vertebræ continue to transmit, and by which alone we are guided from the segment of the endoskeleton to that of the neural axis which originally governed its development.

So, likewise, at the opposite end of the skeleton, we trace the relation of the anterior osseous segment, which transmits the olfactory nerves to their capsule, to its proper segment of the neural axis, by following those nerves back to the retracted ganglions (rhinencephala) from which they take their origin. The connections of the annular frontals of the python with the parietals and post-frontals behind, with the connate orbitosphenoids, and through them with the presphenoid below, prevent their homology being mistaken; for they are far from completely representing or repeating the essential characters of the coalesced annular prefrontals of the frog.

Not to lengthen unnecessarily this exposition of the homologues of the prefrontals (14, figs. 4 and 5) in fishes, I pass at once to the highest of existing reptiles, the crocodile. Here we find, in the dry skull, the condition of the cranial

* No one could better appreciate the value of the functional character of the lacrymal perforation in a homological discussion than Cuvier, when the more obvious features of the prefrontals of fishes were so repeated in any higher animal as to have led him to distinguish the prefrontals in that animal from the lacrymal bone. Thus with regard to the prefrontals of the crocodile, Cuvier says, "Quant à M. Spix, entraîné par un autre système et négligent le trou lacrymal, qui cependant est bien visible, et qui, spécialement dans le crocodile, est percé tout entier dans l'os auquel je donne ou plutôt auquel je maintiens le même nom, c'est mon frontal antérieur qu'il appelle lacrymal." (Ossemens Fossiles.) Change python for crocodile and Cuvier for Spix, and the criticism equally applies in the present instance to its original author.

in that reptile, as the prefrontals are in fishes, chiefly concerned in closing the anterior end of the cranial cavity, in giving exit to the olfactory nerves, in suspending the palatine arch, in connecting the vomer with the nasal vertically, and the nasal with the frontal and lacrymal horizontally, repeating in the crocodile for the latter purpose the development of the upper or horizontal plate which had almost or entirely disappeared in some of the intervening forms of reptiles. In most chelonians this portion of the prefrontal coalesces or is connate with the short nasal: but I have found the instructive exception presented by the existing freshwater tortoise (*Hydromedusa*) of the persistent suture between the nasals and prefrontals, repeated in two fossil chelonians (*Chelone planiceps* and *Chelone pulchriceps*)*.

Proceeding in the ascensive track of the homologies of the prefrontals, I have selected from the class of birds the skull of the ostrich (figs. 8 and 23), the representative of an aberrant order, in which every deviation from the type of the class that has been supposed to tend towards the *Mammalia*, tends equally or more towards the *Reptilia*†, and in which, conformably with the lower development of the respiratory system, the original sutures of the cranium, or in other words, the signs of the vertebrate archetype on which it is constructed, are longest retained. Were we to cut off the corresponding anterior angles of the frontals, no. 11, to those supposed to represent in mammals the bones we are in quest of, we should have even fewer of their characters than in the higher class alluded to, because the descending orbital plate is less developed, and the frontal, though its general size is much augmented, retains more of its oviparous horizontality as an expanded spine or roof-bone of the cranium.

There is a large bone (fig. 23, 73) bounding the anterior border of the orbit, and from which, as we have seen in the parrots, ossification sometimes extends backwards along the inferior contour of the orbit to the postfrontal. But this bone, besides its repetition of the connections of the lacrymal in the fish and crocodile, resting as in the latter animal upon the true malar bone, is either perforated or grooved by the lachrymal duct, which it defends in its course from the eye to the nose, and has none of the essential characteristics of the prefrontal. But we see on the exterior of the skull of the ostrich and other struthious birds‡, a distinct rhomboidal plate of bone interposed between the frontals and nasals, precisely in the situation in which the upper surface of the coalesced prefrontals appears in the skull of the frog and other anourous batrachians. In a nearly full-grown ostrich's skull, I removed the left frontal, nasal, lacrymal and tympanic bones, and the zygomatic arch, as in fig. 8, and found the facet in question to be the upper and posterior expanded surface of a large irregularly subquadrated compressed bone (*ib.* 14), consisting of two vertical compact plates coalesced at their periphery, and including a loose cancellous texture. The upper and posterior expanded surface of the bone extends a short way back beneath the frontals, descends and closes the anterior aperture of the cranium, and sends out from each side a plate of bone which arches over the olfactory nerves and forms the canals by which they are conducted along the upper part of the orbits. The anterior and upper surface of the bone again expands (at 14′, figs. 8 and 23), and there sustains, and is covered by, the nasal bones, and again overarches, and is sometimes

* Report on British Fossil Reptiles, Trans. Brit. Assoc. 1841, pp. 169, 172.

† The urinary bladder and intromittent organ, *e. g.*: the modification of the feathers in the *Struthionidæ* is a degeneration of a peculiarly ornithic character; but not, therefore, an approximation to the hairy covering of mammals.

‡ In the emeu (*Dromaius ater*) at 14, fig. 1. pl. 39. Zool. Trans. t. iii.: and in the cassowary at *h*, fig. 3, taf. i. in Hallmann's 'Vergleichende Osteologie des Schläfenbeins.'

perforated by the olfactory nerves (the course of which along the intracephalic continuation of the cranial cavity, is shown by the arrows, pl. 14, figs. 8 and 23) prior to their final expansion on the olfactory organ; the main body of the bone forms the fore-part of the interorbital septum and the back part of the nasal septum, a slight outstanding ridge or angle dividing the two surfaces: it rests below upon the rostral prolongation of the presphenoid, which, however, barely divides it from the semicylindrical grooved vomer (12) which sheathes the under part of that process. The posterior extremities of the palatines develope broad horizontal plates mesiad and upwards (fig. 23, 20), which join the lower border of no. 14, where it rests upon the presphenoid. The outer margins of the anterosuperior expansion of no. 14 come into contact with the lacrymals: the posterior border of the vertical or rhinencephalic plate joins and soon coalesces with the orbitosphenoids (10). Thus we have all the essential characters of the prefrontals in the fish, the frog and the crocodile, with a repetition of their first important modification in the tail-less batrachians, viz. that of median confluence; and it is not unimportant to observe that this is associated with the obliteration of other cranial sutures, by which also those batrachians resemble birds. The first step in the progress of this median approximation of the prefrontals, is the development of the plates which, in certain fishes, convert the olfactory grooves into foramina; these mesial plates next come into contact at the middle line, *e. g.* in *Xiphias* and *Ephippus*; they proceed to coalesce in the frog, and the prefrontals are so much further compressed in the bird that the olfactory grooves open upon the outer or lateral instead of the inner or mesial surfaces of the rhinencephalic plates: they are, however, very deep grooves in the ostrich, and in the apteryx are canals protected by a distinct external plate. The interruption of the direct vomerine connection by the prolonged presphenoid is the chief secondary modification of the prefrontals in the bird. No other bone in the bird's skull repeats the more essential characters of the prefrontals in fishes and reptiles, save the bone no. 14, figs. 8 and 23. Cuvier calls this bone the 'ethmoïde'; but blames the clear-sighted and consistent German anatomists who applied that name to the prefrontals in fishes and reptiles; yet the part of Cuvier's ethmoid in the bird answering to the 'lamina cribrosa' of the mammal, sometimes gives passage to the olfactory nerve by a single foramen, sometimes by merely a groove, a difference which does not prevent him adopting the homology here, though he opposes it to the adoption, by Bojanus, of the homology of the same part in the fish (*ante*, p. 215). The smooth plate forming, with the orbitosphenoid, the interorbital septum, is the 'os planum,' or papyraceous plate of the bird's ethmoid, with Cuvier: the masking of this part in most mammals by the downward development of the orbital plates of the frontal, offered no difficulty to the ethmoidal determination of no. 14 in the bird; and it forms as little valid objection to Oken's mode of expressing the ethmoidal homology of the prefrontals in the cold-blooded ovipara.

For the reasons before assigned, viz. that the terms 'frontal antérieur' had been given to the bone in question, no. 14, in those animals in which it deviates least from its general type, as the nasal neurapophysis, I retain the name prefrontal for it under all its metamorphoses. Cuvier, after balancing the characters of the bones nos. 15, 22 and 72 (fig. 23) in birds, inclines to the opinion that 15 is the true nasal, and 22′ an essential part (nasal process) of the premaxillary: with regard to 72, he says, "les os externes et plus voisins de l'orbite seraient presque comme on le voudrait, ou des frontaux antérieurs ou des lacrymaux." In which case, no. 14 having been described as the 'ethmoid,' one or other of the above-named bones would be wholly absent

in birds. "Ce que pourrait faire croire que c'est le frontal antérieur qui manque, c'est que dans les oiseaux il n'y a point de frontal postérieur, et que la paroi antérieur de l'orbite, à l'endroit ou le frontal antérieure se trouve ordinairement, est manifestement formée en grande partie par une lame transverse de l'ethmoïde*." But the postfrontal is not always absent in birds: it is present as a distinct bone, though small, in the emeu's skull, figured in the 'Memoir on the *Dinornis*' above-cited; and it is still more developed in the remarkable extinct (?) genus, the immediate subject of that memoir. Besides, to anticipate the subject of a subsequent part of this report, a parapophysis always disappears from a typical segment of the skeleton sooner than a neurapophysis. The rest of Cuvier's difficulty in the recognition of the prefrontal in birds was more nominal than real.

The ethmoid, in the restricted sense in which Cuvier applies the term in the crocodile and other animals with divided prefrontals, and in which I would apply it in those animals also in which the prefrontals have coalesced, is present but remains cartilaginous in the bird. In the mammal it becomes bony and contracts anchyloses not only with the still more reduced debris of the coalesced prefrontals, but also, in consequence of the change of position of the prefrontals through the further progress of concentration, whereby they are drawn backwards closer to the prosencephalic part of the cranium, and in consequence of the concomitant expansion of the true frontals,—with the orbital plates of the frontals; whereby these plates usurp in most mammals the office and the position of the external parts of the prefrontals in the cold-blooded vertebrata†.

The posterior part of the coalesced prefrontals (figs. 24 & 25, 14) divides the anterior aperture of the cranium into two outlets, upon the inner circumference of which the rhinencephala rest; each outlet being commonly closed by part of the olfactory capsules, which are ossified and perforated to receive the divisions of the olfactory nerves. When the prefrontals extend backwards and beyond the cribriform plates, they form what is termed the 'crista galli': this exists in comparatively few mammalia; but is as large in the seal tribe as in man. In the tapirs the prefrontals expand above and overarch the olfactory capsules, but their upper horizontal plates are overlapped by the nasals and true frontals. In the *Delphinidæ*, where the olfactory capsules are absent, the prefrontals expand posteriorly, and diverge from their median coalesced portions constituting the septum of the nasal passage, in order to form the posterior boundaries of those passages and the anterior wall of the cranial cavity. They again expand and form a thick irregular mass anterior to the nasal passages in some *Delphinidæ*, and in *Ziphius* ossification extends along the fibrous continuation of the prefrontals forwards to near the end of the premaxillaries‡. They are connate with the orbitosphenoids behind, and soon coalesce with the vomer below; they rise anterior to the frontals and support the stunted nasals which are wedged between the prefrontals and frontals. The cetacea are the only mammalia in which the prefrontals appear upon the exterior of the skull, and which in this respect resemble the reptilia.

* Leçons d'Anat. Comp. 1837, t. ii. p. 580.

† Cuvier takes this ground in objecting to Oken's ethmoidal homology of the prefrontal in the crocodile, and says, "the ethmoid coexists in a cartilaginous state with, and is enveloped by, the prefrontal, 'comme la partie antérieure du frontal enveloppe l'ethmoïde des ruminans.'"—Hist. des Poissons, v. p. 235. The correspondence is exaggerated, but it matters not. There are other characters of the mammalian ethmoid, as the closing of the cranium anteriorly, the transmitting the olfactory nerves, &c., which are nowise manifested by Cuvier's cartilaginous 'ethmoïde' in the crocodile, and are very satisfactorily so by the prefrontals in that animal.

‡ Ossem. Foss. v. pt. i. p. 351.

Cuvier describes the posterior and superior expanded and diverging plates of the prefrontals as "la lame cribreuse de l'ethmoïde:" the coalesced part forming the septum, he ascribes to the vomer*. Dr. Köstlin†, also, who rightly recognises the ethmoid to be no proper bone of the skull, but only an ossified organ of sense, yet describes, after the anthropotomists, the coalesced prefrontals as the cribriform and azygos processes of the ethmoid ('Siebplatte' and 'Scheidewand des Siebbeins,' pp. 85. 89) in cetacea which have no organ of smell. In a young balænoptera, in which the frontals, the vomer and the nasals were ossified, I find the prefrontals as two cartilaginous plates, extending from the nasals above to the groove of the vomer below. In the manatee the essential parts of the prefrontals which close the cranial cavity anteriorly, and give exit to the olfactory nerves, are thick and unusually expanded. But in no mammal do these parts, with their continuation, the 'lamina perpendicularis,' which, as the coalesced neurapophysial plates of prefrontals, bring the vomer below in connection with the nasals above, ever undergo such modifications as to obliterate their true and essential homological characters.

In proceeding next to consider the special homologies of the bones of the arch closed by the premaxillaries (22) and constituting the 'upper jaw,' I commence with the palatines (20), because they form, throughout the vertebrate series, the most constant medium of suspension of that arch to the anterior cranial segment formed by the vomer, prefrontals and nasal. This 'secret affinity,' as Goethe would have termed it, before the knowledge of the general type had revealed its nature, is manifested by the process of the palatine in man, which creeps up, as it were, into the orbit to effect its wonted union with the prefrontal, to that part of the bone, viz. of which Cuvier had recognised the homologue in his 'ethmoïde' of the bird‡. It is the very constancy, indeed, of these and other connections which has exempted the palatine from the different determinations and denominations attached to other bones, and which renders further discussion of its special homology unnecessary here.

Passing over, for the same reason, the maxillary (21) and premaxillary (22), and referring to the excellent treatise by Dr. Köstlin§ for the grounds of the determination of the 'pterygoid' (24), I proceed to notice other bones which, diverging from the maxillary arch, serve to give it additional fixation and strength in the air-breathing vertebrates. The first of these is the malar bone (fig. 11, 26), the homology of which has been traced without difference of opinion throughout the mammalian class; where, however, the inconstancy of its proportions, number of connections, and very existence, is sufficient to indicate its comparative unimportance as an element of the maxillary arch. It is absent in many insectivores (*Centetes*, *Echinops*, *Sorex*): it has not been detected as a distinct bone in the zygomatic arch in the monotremes, on account perhaps of its early coalescence, as in birds, with the maxillary (fig. 12, 21, 26): in *Myrmecophaga gigantea* and *Manis*, it projects backwards, as a styliform appendage, from the maxillary, but does not attain the squamosal; whilst in the sloths and their extinct congeners the gigantic megatherioids, the malar presents its maximum of development and complexity‖. In the *Delphinidæ*, again, the malar is much reduced: its slightly expanded maxillary end forms part of the orbit and joins the frontal; the rest extending backwards, as a very slender style, beneath the orbit to the squa-

* Ossem. Foss. v. pt. i. pl. xxvii. fig. 3, *h*.
† Der Bau des Knöchernen Kopfes, p. 11.
‡ See the passage above quoted from the 'Leçons d'Anat. Comp.' ii. p. 580.
§ *Op. cit.* p. 328. ‖ Description of the *Mylodon robustus*, 4to, p. 19.

mosal. The malar joins the post-orbital process of the frontal in the *Manatus senegalensis*, the hippopotamus, the solipeds, and ruminants, some carnivores and the lemurs; in the true quadrumanes and man it joins the alisphenoid, and sometimes also the parietal.

The presence, form and connections of the malar are much more constant in the class of birds; where, however, it must be sought for as an independent bone at an early period. In the young ostrich (fig. 23, 26) it is reduced to the form of a simple, straight, slender style, and coalesces first with the similarly-shaped squamosal (27), and next with the malar process of the maxillary (21″). In the crocodile the malar bone (fig. 22, 26) becomes more developed, and adds the connections with the postfrontal (12) and the ectopterygoid (24′) to the more constant ones with the maxillary (21) and squamosal (27), which alone sustain it in birds. In most of the chelonians the malar presents the same connections as in the crocodile, but is transmuted from a 'long' to a 'flat' bone. It retains the expanded shape in the agama; but in most other lizards it resumes the styloid form; being broadest, however, in those genera, *e. g. Iguana*, *Thoractes*, *Tejus*, in which it extends from the maxillary to the postfrontal and squamosal; in the *Varani* it projects freely backwards, like a styliform appendage of the maxillary, as in the toothless mammalian *Bruta*, above-cited.

There is no malar bone in ophidians and batrachians. The lower portion of the tympanic pedicle in the *Anoura* sends forward a process which joins a backward prolongation of the maxillary: in all other batrachia the lower portion of the tympanic pedicle is restricted to its normal connections and to its function of affording articulation to the lower jaw. With regard, therefore, to the zygomatic modification of this portion of the pedicle in anourous *Batrachia*, some may deem it the homologue of the malar; and, in marsupial quadrupeds, the malar actually forms part of the glenoid cavity for the lower jaw: or it may be regarded as the squamosal, which constantly supports the lower jaw in mammals: or it may be viewed as the coalesced homologue of both bones: or finally, as a simple modified dismemberment of the tympanic pedicle of the higher reptiles and birds; effecting a union with the maxillary bone which makes it analogous to, but not, therefore, homologous with, the distinct malar and squamosal in those higher vertebrates. This is a question of special homology on which I am unwilling at present to express a decided opinion: but viewing the inconstancy of the squamosal in reptilia, and its deprivation of the function of exclusively supporting the mandible in all ovipara, I am disinclined to adopt the idea of its sudden restitution to that mammalian function in frogs and fishes; yet, if either of the bones 26 and 27 are to be selected as the homologue of the hypotympanic (23*d*) of batrachians and fishes, I should regard the claims of the squamosal to be stronger than those of the malar, which Cuvier has chosen. The further subdivision, however, of the tympanic pedicle in fishes, prepares us, in the ascensive comparison, for the simple division of the pedicle in batrachia, and for recognising in the lower articular portion a vegetative dismemberment of 28 in the crocodile.

The characters and chief changes, in respect of connections and functions, of the squamosal (27) in the mammalia have already been noticed in the discussion of the homologies of other elements of the complex 'temporal bone' in that class. In birds the bone (fig. 23, 27) undergoes the same change of form which has been noticed in the jugal, viz. from the squamous to the styloid. It continues, however, to connect the malar with the tympanic as it does in figs. 11 and 12, but it has no connections with other bones. Cuvier having been led to recognise the squamosal in the mastoid (fig. 23, 8) of

birds, does not distinguish 27 from 28, the true 'jugal:' and Geoffroy viewing the 'portion écailleuse' of the temporal in that cranial bone of the bird, which he figures under the letter R, fig. 17, pl. 27 (Annales du Muséum, x.), calls the true squamosal, the original separation of which from the malar he had noticed in the chick, 'jugal postérieure.' He did not admit that this division of the zygomatic style was constant or common in the osteogeny of the skull of birds: but I have always found such division in the embryo, and it continues longer than usual in those very species, *e. g.* the duck and ostrich (fig. 23, 28, 27), in which Geoffroy denies its existence (*l. c.*, p. 361). Oken accurately describes the two constituents of the zygoma in the skull of the goose, in his characteristic and original Essay*, where he calls the posterior piece (27) the humerus, and the anterior one (28) the radius of the head. Bojanus†, who also recognised the fact of the essential individuality of the bone (27) in birds, but who saw the homologue of the squamosal rather in the tympanic (28), calls it 'os zygomaticum posterius.' I could cite other testimonies to the primitive existence of the distinct bone in birds connecting the malar with the tympanic; but the fact which chiefly concerns us here is, that if the special homology of no. 8 with the mastoid, and that of no. 28 with the tympanic be proved, we then have a bone presenting the most constant connections of the squamosal in no. 27: if, however, that name be transferred, as has been done by Cuvier, Bojanus‡ and Geoffroy, to other bones, then a new bone and a new name must be introduced into vertebrate craniology, for which, as I trust I have shown, there is no sufficient ground.

Both Oken and Bojanus rightly discern in the permanently distinct bone which, in the crocodiles (fig. 22, 27) and chelonians, connects the malar (28) with the tympanic (28), the homologue of the bone they call 'cranial humerus,' or 'zygomaticum posterius' in the bird. Cuvier is more accurate in his determination of this bone (fig. 23, 27) as the 'squamosal' in reptiles; but again at the expense of his consistency in regard to the characters of his squamosal in the bird: for the homology of no. 8 (Cuvier's 'squamosal') in fig. 22 with no. 8 (Cuvier's 'mastoid') in fig. 23, is as obvious and unmistakeable as is that of no. 27 (Cuvier's 'squamosal') in fig. 22 with no. 27 (his dismemberment of the jugal) in fig. 23. The squamosal is relatively stronger in crocodiles than in birds, and in many chelonians resumes its flat, scale-like form; although, as Cuvier well observes, it answers, in function, only to the zygomatic part of the mammalian squamosal:—"c'est un temporal dont la partie crâniale a disparu§." In lizards the squamosal again resumes the zygomatic or styloid shape, connecting the mastoid and tympanic with the postfrontal, and usually also with the malar; the posterior connections being here, as in mammals, the more constant ones.

As the squamosal varies in form with the malar, so it likewise disappears with it in ophidians; unless the anatomist, tracing it descensively, prefers to see it again in the peculiarly developed hypotympanic of the anourans. According to this view of the sudden resumption of its mammalian function in regard to the lower jaw in batrachia, the name 'squamosal' may be transferred to the hypotympanic in fishes; and, if we must view the pedicle (28 *a—d*, fig. 5) as 'homologically compound,' and not, like the mandibular ramus, 'teleologically compound,' 28*d* seems to me a less arbitrary selection from the pieces of that long and subdivided pedicle, for the representative

* Ueber die Bedeutung der Schädelknochen, 4to, 1807, p. 12.

† Anatome Testudinis Europææ, fol. Parergon, 1821, p. 178, fig. 196, *i*.

‡ The tympanic bone 28 is described in the same work as 'squamosum sive quadratum,' (fig. 196, *g*.): the mastoid is rightly named.

§ Ossemens Fossiles, 4to. t. v. pt. ii. p. 85.

of the squamosal, than the proximal or uppermost piece (28*a*) to which Cuvier has applied that name. If, indeed, Bojanus could have determined to his own satisfaction or that of other anatomists, that the pedicle (28, fig. 23), articulated by one end to the mastoid, and by the other to the mandible, in birds, was the 'squamosum,' then there would have been some ground for regarding the bone (28*a*, fig. 5) connected in fishes, with the mastoid as the 'squamosum.'

But when Cuvier had persuaded himself that the bone no. 8, fig. 23, in birds, to which the tympanic pedicle is articulated, was the 'écaille du temporal,' we feel at a loss to know on what principles special homologies can be traced, when we find the name transferred to the upper part of the tympanic pedicle in fishes (fig. 5. 28 *a*), which is articulated to the bone (8) unequivocally answering to Cuvier's 'écaille du temporal' in birds. M. Agassiz is more consistent, and abandons with reason the Cuvierian determination of the squamosal in fishes: if, however, the grounds assigned are conclusive as to the homology of no. 8, figs. 8 & 23 in birds with the mastoid of mammals and reptiles, M. Agassiz cannot be correct in regarding the bone no. 8, fig. 5 in the fish, as the 'écaille du temporal.'

With reference to the idea entertained by Spix, Geoffroy and Agassiz, of the homology of the suborbital muciferous scale-bones in fishes with the malar bones of higher vertebrates, I may refer to what has already been said in regard to the actual repetition of the osseous arch connecting the prefrontal with the postfrontal in certain birds, where that arch coexists with, and independently of, the bone recognised as the 'malar' by both Spix and Geoffroy. The connection of the malar with the lacrymal and post-frontal is less constant and characteristic of the bone than that with the maxillary and squamosal. And it may further be remarked, that the functional character of circumscribing a mucous duct, manifested by the lacrymal or anterior end of the upper zygomatic or suborbital arch in the parrot, is superadded to the character of connections in proof that such arch, and not the true zygomatic arch below, is homologous with the suborbital chain of bones in fishes. All these discrepancies as to the jugal and squamosal in fishes arise, in my opinion, out of the circumstance that those bones are *normally* absent in that class; both 26 and 27, figs. 11, 22, 23, 24, 25, being accessory parts, developed only in saurians, chelonians, birds and mammals, for additional fixation of the upper jaw, or for additional expansion of the cranium, or for both purposes*.

According to this view, I regard the tympanic (28) as essentially characterized in the oviparous vertebrates (fishes, reptiles, birds) by its free articulation by a convex condyle with the mastoid above, and by a convex condyle with the mandible below; and I regard its subdivisions in the lowest of these vertebrates, in the same light as the subdivisions of the mandible itself. The formation of the tympanic cavity and support of the tympanic membrane are secondary functions. The tympanic pedicle is essentially a single cranial element, and actually so in all air-breathing vertebrates above batrachians. We see plainly, even in the frog, that the portion which supports the 'membrana tympani' is a mere exogenous process of the pedicle: it has still less the appearance of a distinct part or process in the saurians, chelonians and birds: and when the tympanic is excluded by the squamosal in mammals from its normal office of supporting the mandible, it still manifests its character of

* The inconstant ossicle suspended to the back part of the free extremity of the maxillary in the percoid fishes would have the best claim to homology with the malar, if the further subdivision of the maxillary in the herring and lepidosteus did not indicate it to be a vegetative dismemberment of that bone.

unity, whether it be expanded into a 'bulla ossea,' extended into a long tube or meatus, or both, as in fig. 24, 28, or whether, as in fig. 25, it be reduced to a mere ring or hoop supporting the tympanic membrane, until it coalesces with other parts of the temporal, to form the tympanic or 'external auditory process' of that bone. In no air-breathing vertebrate have I ever found, or seen described, the separation of the part of the tympanic forming the wall of the tympanic chamber from the part supporting the tympanic membrane, or this distinct, save in batrachia, from the part supporting the lower jaw*. The tympanic pedicle is still further subdivided in fishes; but M. Agassiz's original idea of the 'epitympanic' as a dismemberment of the pedicle, which he proposed to call '*os carré supérieur*,' is, in my opinion, much more consistent with nature than his later determination of that bone as the 'mastoid,' or than Cuvier's attempts to find the homologues of both the mammalian 'squamosal' and 'jugal' in the piscine subdivisions of the same pedicle. There is as little ground for making the zygomatic process a distinct element from the squamous portion, as for severing the annular process from the rest of the tympanic. This idea of the zygomatic as an independent piece, which Dr. Köstlin has also adopted, seems to rest only on the mal-determination by Bojanus and Oken of the true squamosal in birds and reptiles as the 'zygomaticum' or 'jugale posterius': and the idea was perhaps further strengthened in the mind of M. Agassiz, by what he deems to be the essential and characteristic function of the squamosal. But its protective cerebral or cranial scale is a peculiarly mammalian development; much reduced in the ruminants and cetacea, and totally disappearing in the oviparous vertebrates. The zygomatic functions and connections are, notwithstanding a few exceptions, as in the scaly *manis* and a few lizards, the essential homological characters of the 'squamosal.' The necessity for forming an opinion of the essential nature and general homologies of the parts blended together in the human 'os temporis' by the ascensive or synthetic method, is strikingly exemplified by the results of the application of M. Agassiz's idea of its nature to his determination of the bones in the head of fishes.

As the palato-maxillary arch in most air-breathing vertebrates supports, according to my views, certain appendages, *e. g.* the malar and squamosal, which are not present in fishes; so, I believe, with Cuvier, that the tympano-mandibular arch supports in fishes, certain appendages, which are not developed in any other class. It is this fact, chiefly, that has led to so much discrepancy in the attempts to determine by reference to bones in higher vertebrates the opercular bones of fishes,—the chief battle-field of homological controversy. All the four opercular bones forming the diverging appendage of the tympano-mandibular arch (fig. 5, 34 to 37) were deemed by Cuvier to be peculiar ichthyic super-additions to the ordinary vertebrate skeleton; whilst by Spix, Geoffroy, and De Blainville they are held to be modifications of parts which

* M. Agassiz applies the subjoined analysis of the 'temporal bone' to elucidate the homologies of the skull of fishes:—"Nous distinguons encore dans le *temporal complet* les parties suivantes: l'*écaille*, servant de complément à la paroi latérale du crâne dans sa partie postérieure; le *mastoïdien*, servant de rempart postérieur à la cavité tympanal; *la caisse*, logeant les parties principales de la cavité tympanale; *l'anneau tympanique*, servant d'appui à la membrane du tympan; l'*apophyse jugal*, formant l'appui postérieur de l'arcade zygomatique; l'*apophyse styloïde*, offrant une insertion à l'os hyoïde, par laquelle ce dernier se fixe au crâne; et enfin l'*os carré*, formant la surface articulaire sur laquelle la mâchoire inférieure exerce ses mouvemens. La manière variée dont ces différentes pièces se soudent ensemble, se séparent et se combinent, occasionnent ces innombrables variations auxquelles le temporal est sujet dans son ensemble. L'*écaille du temporal* est destinée, comme nous venons de le voir, à protéger les parties cérébrales postérieures de la tête, sur la face latérale du crane."—Recherches sur les Poissons Fossiles, t. ii. pt. 2, 1843, p. 62.

exist in the ordinary or endo-skeleton of other vertebrata. The learned Professor of Comparative Anatomy in King's College, London, who regards this as "the more philosophical mode of considering them*," has briefly stated the homologies proposed by the supporters of this view, viz. that the opercular bones are gigantic representatives of the ossicles of the ear (Spix, Geoffroy, Dr. Grant†): or that they are dismemberments of the lower jaw (De Blainville, Bojanus),—a view refuted by the discovery of the complicated structure of the lower jaw in certain fishes, which likewise possess the opercular bones: he then cites a third view, viz. that they are parts of the dermal skeleton; "in short, scales modified in subserviency to the breathing function;" an opinion which Professor Jones correctly states that he derived from my Lectures on Comparative Anatomy, delivered at St. Bartholomew's Hospital in 1835, and which he adopts, although its accordance with his first proposition is not very clear. I have subsequently seen reason to modify that view, though it has received the sanction of the greatest ichthyologist of the present day, M. Agassiz; and, as I have since found, had presented itself so early as 1826, under a peculiar aspect to the philosophical mind of Professor Von Baer. In his admirable paper on the endo- and exo-skeleton, M. Von Baer expresses his opinion, that the opercular bones are (dermal) ribs or lateral portions of the external cincture of the head‡. The idea of the relationship of the opercular flaps to locomotive organs is presented by Carus, under the fanciful view of their homology with the wing-covers of beetles and the valves of a bivalve shell§. In 1836, M. Agassiz propounded his idea of the relation of the opercular bones to scales in a very precise and definite manner; though, as I have elsewhere shown‖, the chief ground of his opinion is erroneous. He says, "Les pièces operculaires des poissons ne croissent pas, comme les os des vertèbres en général, par irradiation d'un ou de plusieurs points d'ossification; ce sont, au contraire, des véritables écailles, formées, comme celles qui recouvrent le tronc, de lames déposées successivement les unes sous les autres, et dont les bords sont souvent même dentelés comme ceux des écailles du corps. Tels sont l'opercule, le sub-opercule, et

* Professor Rymer Jones, General Outline of the Animal Kingdom, 8vo, 1841, p. 509.

† Lectures, Lancet, Jan. 11, 1834, p. 573; Outlines of Comp. Anat. p. 64.

‡ "In mancher Beziehung gehören die Kiemendeckel zu ihr, und ich halte sie um so mehr für (Haut) Rippen, d. h. für Seitentheile der äussern Ringe des Kopfes, da ich sie auch in den gewohnlichen Knockenfischen für nichts anderes ansehen kann. Hat bei diesen auch der oberste Knochen des Kiemendeckels wenig Aehnlichkeit mit Rippen, so geht dagegen der unterste so unverkennbar in die strahlender Kiemenhaut über, das der Uebergang gar nicht zu verkennen ist."—Meckel's Archiv, 1826, 3 heft, p. 369.

An analogous idea of the relation of the opercular bones to the inferior or costal arches was proposed by Geoffroy St. Hilaire (Annales des Sciences, t. iii. pl. 9), and Cuvier (Hist. des Poissons, i. p. 232), and has been adopted by the learned Professor of Comparative Anatomy in University College, who, speaking of the occipital vertebræ, says, "The two external and the two lateral occipitals form the upper arch, and the two opercular and two subopercular bones constitute the lower arch." (Lectures, Lancet, 1834, p. 543.) He subsequently, however, adopts and illustrates (p. 573) the homology of the opercular bones with the 'ossicula auditûs' of mammalia; and in the 'Outlines of Comp. Anat.' cites only the Spixian and Blainvillian hypotheses (pp. 64, 65). In my Hunterian Lectures (vol. ii. 1836, pp. 113, 130), I have adduced the grounds which have led me to the conclusion that the opercular bones are neither ribs of the exo-skeleton, nor inferior arches of the endo-skeleton, but persistent radiating appendages of an inferior (hæmal) arch; not, however, of the occipital vertebra, but of the frontal; just as the branchiostegal rays are the appendages of the hæmal arch of the parietal, and the pectoral fins of that of the occipital vertebræ. That parts of both endo- and exo-skeleton may combine to constitute the opercular fin is the more probable, inasmuch as we see the same combination of cartilaginous and dermal rays in the pectoral fins of the plagiostomes, and in the median fins of most fishes.

§ Urtheilen des Knochen und Schalengerüstes, fol. p. 122.

‖ Lectures on Vertebrata, p. 139.

l'inter-operculo. Le supra-scapulaire même peut être envisagé comme la première écaille de la ligne latérale, dont le bord est également dentelé. On pourrait dire aussi que le scapulaire n'est qu'une très grande écaille de la partie antérieure des flancs*." And he adds, "L'opinion que j'ai émise à leur égard prouve que je suis loin d'admettre les rapports que l'on a cru trouver entre les pièces operculaires et les osselets de l'oreille interne†."

I apprehend that the idea of the development of the opercular bones by the successive excretion or deposition of layers, one beneath the other, according to the mode in which M. Agassiz supposes scales to be formed, was derived merely from the appearance of the concentric lines on the opercular, subopercular, and interopercular bones in many fishes. I have examined the development of the opercular bone in young gold-fish and carp, and I find that it is effected in precisely the same manner as that of the frontal and parietal bones. The cells which regulate the intussusception and deposition of the earthy particles make their appearance in the primitive blastema in successive concentric layers, according to the same law which presides over the concentric arrangements of the radiated cells around the medullary canals in the bones of the higher vertebrata: and the term 'successive deposition,' in the sense of excretion, is inapplicable to the formation of the opercular bones. The argument in favour of their dermal character drawn from the phænomena of the development of the opercular flap, would equally apply to prove the bones (ulna, radius, carpus, &c.) supporting the pectoral fin, to be 'dermal' bones‡.

The interopercular as well as the preopercular bones exist in the *Lepidosiren annectens* with all the characters, even to the green colour, of the rest of the ossified parts of the endo-skeleton; the preopercular, as an appendage to the tympanic arch, retaining its primitive embryonal subcylindrical form, the interopercular being partly attached to the hyoid arch. Of the suprascapular there is no trace in the lepidosiren; but in the sturgeon it plainly exists as part of the cartilaginous endo-skeleton, under the same bifurcate form, and double connection with the cartilaginous skull, which it presents in most osseous fishes. The large triangular bony dermal scale firmly adheres to its broad, triangular, flat, outer surface. The epi- and meso-tympanic cartilages in like manner expand posteriorly, and give a similar support to the large opercular ganoid scale. Were the supporting cartilages of the opercular and suprascapular scales to become ossified in the sturgeon, they might become anchylosed to the dermal bony plates, and bones, truly homologous with the opercular and suprascapular in ordinary osseous fishes, would thus be composed of parts of the endo- and exo-skeleton blended together. I cannot, therefore, concur with Von Baer in the opinion that the opercular bones are ribs of the exo-skeleton, nor with Agassiz that both the opercular and suprascapular bones are merely modified scales. In explaining my views of the opercular bones, I am compelled, believing them to have no special homologues in higher animals, to express those views in the terms of a higher generalization. The suprascapular bone (fig. 5, 40) is the upper or first part of the hæmal arch of the occipital segment of the skull, and corresponds in serial homology with the epi-tympanic portion (28 *a*) of the mandibular arch, and with the palatine portion (20) of the maxillary arch. The opercular bones are the diverging appendages of the tympano-mandibular

* Recherches sur les Poissons Fossiles, livraison 6me, 1836, tom. iv. p. 69.

† *Ib.* p. 73.

‡ "L'embryologie nous prouve, en effet, que la formation de l'appareil operculaire n'est qu'un simple produit de la peau, qui peu-à-peu s'étend par dessus les branchies, d'abord entièrement dégagées dans l'embryon."—*Ib.* p. 64.

arch, and correspond, in serial homology, with the branchiostegal appendages of the hyoid and the pectoral appendages of the scapular arches, and have the same title to be regarded as cephalic fins, and as parts of the normal system of the vertebrate endo-skeleton; but neither opercular bones nor branchiostegal rays are retained in the skeletons of higher vertebrata. All diverging appendages of vertebral segments make their first appearance in the vertebrate series as 'rays'; and the opercular bones are actually represented by cartilaginous rays, retaining their primitive form in the plagiostomes. In the conger the subopercular still presents the form of a long and slender fin-ray.

The opercular and subopercular, in ordinary osseous fishes, may frequently coalesce, like the suprascapular, with their representative scales of the dermal system; but they are essentially something more than peculiarly developed representatives of those scales. M. Agassiz, indeed, excepts the preopercular bone from the category of "pièces cutanées," believing it to be the homologue of the styloid process of the temporal bone in anthropotomy, or the 'stylo-hyal' of vertebrate anatomy, as the piece, viz. which completes the hyoid arch above. "C'est en effet," he says, "cet os à la face interne duquel l'os hyoide des poissons est suspendu, qui s'articule en haut avec le mastoïdien et très souvent même sur l'écaille du temporal." So far as my observation has gone, it is a rare exception to find the hyoid arch suspended to the preoperculum; the rule in osseous fishes is to find the upper styliform piece of the hyoid arch (fig. 5, 28) attached to the epi-tympanic (28 *a*) close to its junction with the meso-tympanic bone (28 *b*). It is equally the rule to find the preopercular (24) articulated with the epi-, meso-, and hypo-tympanics; and it is an exception, when it rises so high as to be connected with the mastoid ('écaille du temporal' of Agassiz). If the stylo-hyal be not the upper piece of the hyoid arch displaced, and if the upper piece connecting that arch with the mastoid is to be sought for in osseous fishes, I should rather view it in the posterior half of the epi-tympanic (28 *a*), which is usually bifurcate below and very commonly also above, when the posterior upper division articulates with the mastoid, and one of the lower divisions with the hyoid arch.

The normal position, form, and connections of the preoperculum clearly bespeak it to be the first or proximal segment of the radiated appendage of the tympano-mandibular arch: the opercular, subopercular, and interopercular bones form the distal segment of the same appendage.

M. Vogt, in supporting M. Agassiz's views of the Ganoid order, reiterates his original idea that the preopercular bone is the proximal piece (styloid) of an arch distinct from the tympano-mandibular one; but as the chief ground of this opinion rests on a simple question of fact easily determinable, viz. whether, as a rule, the hyoid arch is suspended from the preoperculum, and this from the mastoid in fishes, neither of which accord with my observation of their connections of those parts, the verdict may be left to the experience of other observers. From a remark of M. Vogt's*, viz. that "M. Müller attache, à ce qu'il parait, trop peu d'importance *à ce fait*, que toujours le préopercule, et cela aussi chez les Siluroïdes, sert de point d'attache à l'arc hyoïdien," it would seem that, perhaps, the accomplished physiologist and ichthyologist of Berlin had not found *the fact*; and, therefore, gave not more than its due importance to the rare exceptional circumstance of such an attachment. The preopercular can be removed in most fishes, except where, as in the siluroids, it coalesces with the tympanic arch, without dislocating

* Annales des Sciences, 1845, p. 56.

or disturbing the connections of the true stylo-hyal (fig. 5, 2s) with the epitympanic (2s *a*) from which it is normally suspended.

M. Vogt correctly observes that the 'temporal' (epitympanic, 2s *a*), 'symplectique' (mesotympanic, 2s *b*), and 'jugulaire' (hypotympanic, 2s *d*), "à eux seuls forment déjà un arc suspensoir complet, à la face postérieure duquel le préopercule est seulement accolé*." But this only proves that the preoperculum is an appendage to such arch, not that it is a suspensory pier of a second arch.

The only essential modification which the siluroids present is the confluence of the preoperculum with the true tympanic pedicle, here reduced to a single piece. But this does not disprove its character as an appendage of the tympano-mandibular arch, any more than does the confluence of the ulna and radius with the scapular arch in the sturgeon disprove the character of those elements as appendages of that arch. I have not been able to trace in the siluroids the primitive boundaries of the coalesced preoperculum to such an extent as to justify the statement, that it is intercalated between the epitympanic and hypotympanic, replacing the mesotympanic: but, if the preopercular should extend in any siluroid fish so far as M. Vogt describes, this exceptional development would rather prove it to belong essentially to the tympanic and not to the hyoidean arch: at least it is only through this abnormal encroachment that the preopercular can detach the stylohyal from the epitympanic.

As the otosteals, or 'ossicula auditûs,' have borne a prominent share in the discussions of the special homologies of the tympanic pedicle and its appendages, I may here remark that the extension in the embryo mammal of the long and slender process of the malleus in the direction of the mandible, and its continuation or connection with the cylindrical cartilage (hæmal portion of the tympano-mandibular arch) from which the lower jaw is subsequently developed, is a circumstance which renders the idea of the malleus, at least, being a modified element of the tympano-mandibular arch in batrachians and fishes, worthy of consideration. The prolongation from the mesotympanic of the cylindrical cartilage, described by Meckel, and around which the mandible is ossified in fishes, and the characteristic cylindrical or styloid form of the mesotympanic, have induced M. Vogt† to view that bone, the 'symplectique' of Cuvier, as the homologue of at least part of the malleus; and at the same time of the bone called 'tympano-malléal' by Dugés (my 'hypotympanic') in the batrachians. M. Vogt offers no other reasons for the determination. I find that the cartilage which in the batrachians forms the medium of communication between the semi-ellipsoid ossicle (stapes) closing the fenestra ovalis and the tympanic membrane, is repeated or reproduced in the more malleiform cartilage connecting the columelliform stapes of the saurian reptiles to the membrana tympani. In birds a portion of the cartilage attached to the tympanum becomes ossified and coalesces with the columelliform stapes; and at the angle of union one or two cartilaginous processes exist, which some anatomists have compared with the incus. But all anatomists have concurred in recognising the homology of the peripheral bent-down portion of the long columella, which adheres to the membrana tympani, with the part of the malleus called 'manubrium,' or handle, in mammalia. The superadded modifications characteristic of the otosteals in this class, have their seat between the manubrium mallei and the stapes, and chiefly result in the development of the new bone called 'incus' and its epiphysis, which has been termed the 'os orbiculare.' Notwithstanding, therefore, the connection of the 'processus gracilis mallei' with the embryonic

* Annales des Sciences, 1845, p. 55.

† *Loc. cit.* p. 58.

hæmal or visceral cartilage of the mandibular arch in mammals, the homology of the malleus is so clearly traceable down to its first independent manifestation in coexistence with the tympanic membrane of the batrachia, to which it connects the unequivocally acoustic ossicle representing the 'stapes,' that the reference of all the additional ossicular mechanism of the ear-drum to the same system of the skeleton as the petrosal itself, appears to me to be most consonant with the recognised facts in their development and comparative anatomy.

M. Agassiz has never countenanced the idea of the reproduction of the mammalian tympanic ossicles in a magnified form in either the tympanic arch or its opercular appendages. Returning to the consideration of these bones in the last volume (p. 68) of his admirable 'Recherches,' he reaffirms his opinion, that the opercular, subopercular, and interopercular are 'osselets particuliers de la peau;' but calls them 'branchiostegal rays.' If he had meant that they were parts essentially distinct, but comparable to the true branchiostegals, he would have accurately enunciated their 'serial homology.' M. Agassiz, however, expressly repudiates this idea of representative relation, and affirms them to be part of one and the same series of rays. "Mais en disant que les pièces operculaires sont des rayons branchiostègues, je n'entends point faire une simple comparaison, mais bien affirmer, que je considère ces plaques osseuses simplement comme les rayons branchiostègues supérieurs*." This idea is, in fact, a necessary consequence of M. Vogt's conclusion, that the preoperculum is the upper or styloid element of the hyoidean arch. The combination of the opercular rays or bones with the branchiostegals in the support and movements of the continuous gill-cover and gill-membrane, does not prove them to be diverging appendages of the same arch, any more than the similar combination of the rays of the pectoral and ventral fins in the sucker of the *Cyclopterus* proves those rays to be parts of the same arch. And I may repeat that, admitting the humerus to be, as Bakker surmised, confluent in all fishes with the bone 32, fig. 5; and since in the plagiostomes, sturgeons and lophioids, the second segment of the rudimental fore-limb is not liberated from the supporting arch; so, likewise, the proximal member of the opercular limb may remain, or become in some instances confluent with its sustaining arch, without that exceptional state invalidating the determination deduced from its more constant and regular character as the proximal element of the free appendage to that arch.

The third inverted arch of the skull is suspended in fishes by a slender styliform bone, the 'stylohyal' (fig. 5, 33), from the lower end of the epitympanic (33 *a*) close to the joint of the styliform 'mesotympanic' (33 *b*); and it is connected, through the medium of the posterior division and joint of the epitympanic, with the mastoid (3). Now, either that division of the epitympanic may be viewed, by virtue of its proper articular condyle above, and its connection with a distinct inverted arch below, as the proximal piece of that arch, coalesced with the proximal piece of the next arch in advance, which articulates with the post-frontal; or, it may be viewed as an excessive development of the proximal piece of the tympano-mandibular arch, which, extending backwards, has displaced the hyoid from the mastoid, just as the squamosal, by a similar backward development, in mammals, displaces the mandibular arch from the tympanic.

According to the first view, the bone no. 33 would be a dismemberment of the proximal element of the hyoid arch; according to the second view, it would be the entire element reduced and displaced: in both cases it would be homologous with the proximal slender piece of the hyoid arch in all

* Recherches sur les Poissons Fossiles, v. pt. ii. p. 68.

vertebrata, and to which piece the term 'styloid' or 'stiliform' has been given from the fish up to man (see TABLE I.). The homology, indeed, is so obvious, that M. Agassiz, in accepting the conclusion of M. Vogt, that the bone (fig. 5, 34), peculiar to osseous fishes, which so rarely articulates directly with the mastoid or with the hyoid arch, and so constantly sustains the distal segment of the operculum, was the homologue of the 'processus stiliformis ossis temporis,' nevertheless retains the name 'styloïde' for the part no. 28 in question.

The true homology of no. 34, already explained, removes the anomaly of viewing that peculiarly piscine bone as the homologue of a constant element of the hyoid arch in all the vertebrate classes, and the greater anomaly of the introduction of a new element—a styloid piece of the os hyoïdes—in addition to the 'styloid process of the temporal' in fishes. The 'stylohyal' articulates below to the apex of a triangular piece (39), which is pretty constant in fishes, and to which I give the name of 'epihyal,' as being the upper of the two principal parts of the cornu or arch: the third longer and stronger piece is the 'ceratohyal' (*ib.* 40).

The keystone or body of the inverted hyoid arch is formed by two small subcubical bones on each side, the 'basihyals' (*ib.* 41). These complete the bony arch in some fishes: in most others there is a median styliform ossicle, extended forwards from the basi-hyal symphysis into the substance of the tongue, called the 'glossohyal' (*ib.* 42), or 'os linguale'; and another symmetrical, but usually triangular, flattened bone, which expands vertically as it extends backwards, in the middle line, from the basihyals; this is the 'urohyal' (*ib.* 43). It is connected with the symphysis of the coracoids, which closes below the fourth of the cranial inverted arches, and it thus forms the isthmus which separates below the two branchial apertures. In the conger the hyoidean arch is simplified by the persistent ligamentous state of the stylohyal, and by the confluence of the basi-hyals with the ceratohyals: a long glossohyal is articulated to the upper part of the ligamentous symphysis, and a long compressed urohyal to the under part of the same junction of the hyoid arch. The glossohyal is wanting in the *Muræophis*.

The appendages of the hyoidean arch in fishes retain the form of simple, elongated, slender, slightly curved rays, articulated to depressions in the outer and posterior margins of the epi- and cerato-hyals: they are called "branchiostegals," or gill-cover rays, because they support the membrane which closes externally the branchial chamber. The number of these rays varies, and their presence is not constant even in the bony fishes: there are but three broad and flat rays in the carp; whilst the clupeoid *Elops* has more than thirty rays in each gill-cover: the most common number is seven, as in the cod (fig. 30, 44). They are of enormous length in the angler, and serve to support the membrane which is developed to form a great receptacle on each side of the head of that singular fish.

Branchial Arches.—In the class of fishes, certain bony arches, which appertain to the system of the visceral skeleton, succeed the hyoidean arch, with the keystone of which they are more or less closely connected. Six of these arches are primarily developed, and five usually retained; the first four of these support the gills, the fifth is beset with teeth and guards the opening of the gullet: this latter is termed the 'pharyngeal arch,' the rest the 'branchial arches.'

The lower extremities of these arches adhere to the sides of a median chain of ossicles, which is continued from the posterior angle of the basi-hyal, or from above the uro-hyal, when this is ossified: the bones which form those extremities are the 'hypobranchials'; and they support longer bent pieces,

called 'cerato-branchials.' It is with these elements of the branchial arches in fishes and perennibranchiate batrachians that we are chiefly concerned in tracing the homology of the hyoid apparatus in the air-breathing vertebrates. With regard to the branchial and pharyngeal arches, which attain their full development only in the class of fishes, I regard them as appertaining to the system of the splanchno-skeleton, or to that category of bones to which the heart-bone of the ruminants and the hard jaw-like pieces supporting the teeth of the stomach of the lobster belong. The branchial arches are sometimes cartilaginous when the true endo-skeleton is ossified: they are never ossified in the perennibranchiate batrachians, and are the first to disappear in the larvæ of the caducibranchiate species; and both their place and mode of attachment to the skull demonstrate that they have no essential homological relation to its endo skeletal segments.

The hyoid arch or apparatus retains most resemblance to that of fishes in the *Siren lacertina*; the basihyal is simplified into a single osseous spatulate piece, with the bowl of the spoon anterior, and supporting a broad and flat semicircular glossohyal. A strong and thick ceratohyal is articulated by means of a small cartilage to the side of the expanded part of the basihyal, and a cartilaginous epihyal arches backwards from its upper end. A cartilaginous urohyal extends from the hind end of the basihyal, and expands into a radiated disc, which supports the membranous trachea and the simple glottis. One pair of bony 'hypobranchials' is articulated to the basi-uro-hyal joint and a second pair to the sides of the urohyal: and to the upper and outer ends of these are attached four pairs of cartilaginous 'ceratobranchials.' The fimbriated branchiæ are attached to the three anterior ceratobranchials.

In the proteus the urohyal is absent, and it is not again developed in any batrachian. The long subcylindrical basihyal supports a subcircular cartilaginous discoid glossohyal, and at the angle of union the bony ceratohyals are sent off. A pair of hypobranchials diverge from the end of the basihyal; to which a second small pair of basibranchials are loosely connected by an aponeurosis. These support three ceratobranchials on each side, which are bony.

In the newts there is neither a glossohyal nor urohyal, or but a rudiment of the latter, to each side of which are articulated two hypobranchials, whose distal ends converge on each side to support a single cartilaginous gill-less rudiment of a ceratobranchial. The special homologies of all those parts of the complex hyoid, rendered more complex by the retention of part of the branchial skeleton, are clearly demonstrated by pursuing the metamorphoses of the hyo-branchial skeleton in the larvæ of the anourous batrachians. In the full-gilled tadpole a short and simple basihyal supports laterally two thick and strong ceratohyals, and posteriorly two short and broad hypobranchials, to which four ceratobranchials are attached: all the parts are cartilaginous. The type of this stage is retained in the siren, with the histological progress to bone in the hyoid and hypo-branchial pieces. The second well-marked stage in the tadpole shows an extension of the external and posterior angles of the hypobranchials, with progressive absorption of the cartilaginous ceratobranchials. The growth and divergence of the posterior angles of the hypobranchials refer to the development of the larynx, now commencing, which part they are destined to support. That period may be described as the third stage at which the ceratobranchials have disappeared, and the posterior angles of the hypobranchials increase in length and assume the character of posterior cornua of the os hyoides. The last and adult stage shows the ossification of the elongated angles of the hypobranchials,

the coalescence of their cartilaginous bases with the basihyal, the expansion of the basihyal and extension of its anterior and external angles; in front of which the now long and slender ceratohyals usually coalesce with the basihyal; their opposite ends having shifted their attachments and retrograded, like other hæmal arches of the skull, in the course of the metamorphosis. In the case of the hyoid arch of the frog, the change of place is from the tympanic pedicle backwards to the persistent cartilaginous petrosal: and this is a very suggestive and significant change. All the parts of the hyoid remain cartilaginous except the appended and persistent detachments from the visceral system of the branchial arches: these long 'hypobranchials' ('cornes thyroïdiennes' of Cuvier and Dugés) diverge and include the larynx in their fork. The relative position, connexions and office in subserviency to the larynx, to which the retained parts of the splanchno-branchial arches are introduced in the lowest of the air-breathing vertebrates, are preserved in all the higher classes. The 'hypobranchials' are as constant in their existence, therefore, as the upper larynx itself, and attach themselves more especially to the thyroid element of that larynx. We recognise them by this relation in birds and man (46, figs. 23 and 25), where they always much exceed the parts of the true hyoid arch (cerato- and epi-hyals) in length; and in birds, where these elements (40, fig. 23) are sometimes obsolete and always rudimental, the hypobranchials have been mistaken by both Cuvier and Geoffroy* for the ceratohyals or anterior cornua.

For the modifications and special homologies of the complex hyoid apparatus in lizards, I refer to my 'Lectures on the Vertebrata.' The crocodiles offer a well-marked ordinal difference from those inferior sauria in this as in most other parts of their structure. The basihyal and thyrohyals have coalesced to form a broad cartilaginous plate, the anterior border rising like a valve to close the fauces, and the posterior angles extending beyond and sustaining the thyroid and other parts of the larynx. A long bony 'ceratohyal' (fig. 22, 40), and a commonly cartilaginous 'epihyal' (*ib.* 39), are suspended by a ligamentous 'stylohyal' to the paroccipital process; the whole arch having, like the mandibular one, retrograded from the connection it presents in fishes.

In birds as in chelonians, the ceratohyals are much reduced, and the chief 'cornua' of the hyoid are represented by the hypo- and epi-branchials (thyrohyals), which here attain their maximum of length and tenuity. The basihyal (fig. 23, 41), as in *Chelys*, is long and slender, but is always a simple piece; and, as in lizards, is usually most expanded posteriorly, from which expansion the thyrohyals (46) are sent off. Conforming with the long and slender tongue in most birds, the basihyal extends forwards, and is articulated with the rudimental ceratohyals (40), when these exist, at some distance from the thyrohyals. A commonly long and slender, sometimes spatulate glossohyal (42), is articulated to the fore-part of the basihyal; and a constantly long, slender and pointed urohyal (43) is articulated with the posterior end of the basihyal, and extends backwards beneath the trachea. The thyrohyals (46) diverge and include the larynx in their fork; and support at their extremities a bony or gristly (cerato-branchial) style (47). This is never attached by ligament to the base of the skull, but is suspended freely, as in the chelonia, by the glossohyoid and omohyoid muscles; it, however, curves over the back and upper part of the cranium in the woodpeckers, and the extremities of both cerato-branchials are inserted, by way of rare exception in that bird, into the right nostril.

* Dugés appears to have first pointed out this error, but without, however, perceiving the true homology of his 'cornes thyroïdiens' with the hypobranchials of fishes.

In mammals the normal completion of the hyoidean arch, as it first appears in fishes, is again resumed, and that not by a slender cartilage, as in the frog, but by a chain of bones, in which we again recognise the cerato- (fig. 24, 40), epi- (39) and stylo- (38) hyals suspending the basihyal (41) and the tongue to the base of the skull, often to the petrosal, sometimes to the tympanic, or to the mastoid, or to the exoccipital. The ungulates and the true carnivora best display this type.

In man (fig. 25) the ceratohyals are reduced, as in birds, to mere tubercles of bone (40), and the extent of the arch between them and the stylohyals, which become anchylosed to the temporal bones, retains its primitive ligamentous condition. Occasionally, however, ossification extends along the stylohyoid ligament, and marks out, as in the specimen figured by Geoffroy St. Hilaire (Philosophie Anatomique, pl. 4, fig. 87), the more normal proportions of the ceratohyal, and also the epihyal. Other examples of this 'monstrosity' are recorded in works on anthropotomy. The thyrohyal (46)—the last remnant of the branchial arches—maintains more constancy in its existence and proportions; but manifests its true character of free suspension below the skull, and an articulation by short ligaments to the angles or horns of the thyroid cartilage.

The remarks already made on the special homologies of the parts of the scapular arch and its appendages, preclude the necessity of further extending the present part of this Report.

Part II.—General Homology.

On taking a retrospect of the results of the researches of anatomists into the special homologies of the cranial bones, the student of the science, how little soever practised in such inquiries, cannot but be struck with the amount of concordance in those results. It must surely appear a most remarkable circumstance to one acquainted only with the osteology of the human frame, that so many bones should be, by the common consent of comparative anatomists, determinable in the skull of every animal down to the lowest osseous fish. This fact alone, so significant of the unity of plan pervading the vertebrate structure, has afforded me, at least, a large ground of hope and much encouragement to perseverance in the reconsideration of those points on which a difference of opinion has prevailed; and in the re-investigation of what is truly constant and essential in characters determinative of special homologies.

In this, as in every other inquiry into nature, the first labours are necessarily more or less tentative and approximative: but if errors have to be eliminated in the course of successive applications of fresh minds to the task, truths become confirmed and established. And I regard the body of such truths (see Table I.) to be now so great, in respect of the determination of the homologous bones in the heads of all vertebrate animals, as to imperatively press upon the thinking mind the consideration of the more general condition upon which the existence of relations of special homology depends.

Upon this point the anatomical world is at present divided, lacking the required demonstration. The majority of existing authors on comparative anatomy have tacitly abandoned*, or with Cuvier and M. Agassiz, have

* Wagner, 'Lehrbuch der Zootomie,' 8vo, 1843, 1844. Siebold and Stannius, 'Lehrbuch der Vergleichende Anatomie,' 8vo, 1845, 1846. Milne-Edwards, 'Elemens de Zoologie,' 8vo, 1834. Prof. Rymer Jones, 'Outline of the Animal Kingdom and Manual of Comparative Anatomy,' 8vo. 1841. The sentiments which this pleasing and instructive writer expresses, are probably akin to those which have influenced the above-cited authors

directly opposed the idea of 'special homology' being included in a higher law of uniformity of type.

Yet the attempt to explain, by the Cuvierian principles, the facts of special homology on the hypothesis of the subserviency of the parts so determined to similar ends in different animals,—to say that the same or answerable bones occur in them because they have to perform similar functions—involve many difficulties, and are opposed by numerous phænomena. We may admit that the multiplied points of ossification in the skull of the human fœtus facilitate, and were designed to facilitate, childbirth; yet something more than such a final purpose lies beneath the fact, that most of those osseous centres represent permanently distinct bones in the cold-blooded vertebrates. The cranium of the bird, which is composed in the adult of a single bone, is ossified from the same number of points as in the human embryo, without the possibility of a similar purpose being subserved thereby, in the extrication of the chick from the fractured egg-shell. The composite structure is repeated in the minute and prematurely-born embryo of the marsupial quadrupeds. Moreover, in the bird and marsupial, as in the human subject, the different points of ossification have the same relative position and plan of arrangement as in the skull of the young crocodile, in which, as in most other reptiles and in most fishes, the bones so commencing maintain throughout life their primitive distinctness. These and a hundred such facts force upon the equal and knowing anatomist the inadequacy of the teleological hypothesis to account for the acknowledged concordances expressed in this report by the term 'special homology.' If, therefore, the attempt to explain them as the results of a similarity of the functions to be performed by such homologous parts entirely fails to satisfy the conditions of the problem; and if, nevertheless, we are, with Cuvier, to reject the idea of their being manifestations of some higher law of organic conformity on which it has pleased the divine Architect to build up certain of his diversified living works, there then remains only the alternative that special homologies are matters of chance.

This conclusion, I apprehend, will be entertained by no reasonable mind; and reverting, therefore, to the more probable hypothesis of the dependence of the special resemblances upon a more general law of conformity, we have next to inquire, what is the vertebrate archetype? The gifted and deep-thinking anatomist, Oken, obtained the first clew to this discovery by

on this subject. "It is not by any means our intention to engage our readers in discussing all the conflicting and, sometimes, visionary opinions entertained by different authors relative to the exact homology of the individual bones forming this part of the skeleton; and we shall, therefore, content ourselves by placing before them, divested as far as possible of superfluous argumentation, Cuvier's masterly analysis of the labours of the principal inquiries concerning this intricate part of anatomy."—p. 494. A later English author, who has embodied a most valuable amount of careful and exact osteological observation in the article "Zoology" of the 'Encyclopædia Metropolitana' (4to, 1845), seems scarcely to regard even the determination of special homologies as a necessary object of anatomical research. Thus, in discussing the differences of opinion respecting the coracoid (fig. 5, 48). he says, "Bakker's view, however, if it be absolutely necessary to hunt up analogies, seems more correct."—p. 302.

This reserve is, however, perhaps less obstructive to the philosophical progress of anatomy and to the requisite resumption of original inquiry to that end, than the mere reproduction of the transcendental views of others without criticism or attempt to explain or refute the objections to such views which have been promulgated by so great authorities as Cuvier and Agassiz. Thus Bojanus's 4-vertebral theory of the cranial part of the skull is adopted by M. De Blainville (Ostéographie, 4to); whilst Dr. Grant (Outlines of Comparative Anatomy, 8vo, 1835, p. 63) deems the composition of the skull, in fishes, to correspond nearly with Geoffroy's theory of this part of the skeleton being composed of seven vertebræ, each consisting of a body with four elements above and four elements below.

the idea of the arrangement of the cranial bones of the skull into segments, like the vertebræ of the trunk. He informs us that walking one day in the Hartz forest, he stumbled upon the blanched skull of a deer, picked up the partially dislocated bones, and contemplating them for a while, the truth flashed across his mind, and he exclaimed "It is a vertebral column!*" Oken afterwards tested and matured this happy inspiration by examining the skulls of a cetacean, a chelonian, and a cod-fish in Dr. Albers's museum at Bremen; and on his return to Jena in 1807, he published his beautiful generalization in a now very scarce Introductory Lecture, or "Programm beim Antritt der Professur," entitled 'On the signification of the bones of the skull'†. He illustrates his views by reference to the skull of a ruminant. "Take," he says, "a young sheep's skull, separate from it the bones of the orbit, also those cranial bones which take no share in the formation of the 'basis cranii,' *e.g.* the frontal, parietal, ethmoid and temporal, and there will remain an osseous column which any anatomist, at first glance, would recognise as three bodies of a kind of vertebræ with transverse processes and foramina. Replace the cranial bones with the exception of the temporals, for, without these, the cavity is still closed, and you have a cranial vertebral column, which differs from the true one ('von der wahren') only by its more expanded neural canal (Ruckenmarkshöhle). As the brain is a more voluminously developed spinal chord, so is the brain-case a more voluminous spinal column. As the cranium includes, then, three vertebral bodies, so must it have as many vertebral arches. These are next to be sought out and determined. One sees the sphenoid divided into two vertebræ; through the foremost pass the optic nerves, through the hindmost the maxillary nerves (*par trigeminum*). I call one the 'eye-vertebra' (Augwirbel), the other the 'jaw-vertebra' (Kieferwirbel). Upon this latter abuts the basilar process of the occipital bone and the petrous bones: both belong to one whole. As the optic nerve perforates the 'eye-vertebra,' and the trigeminus the 'jaw-vertebra,' so the acoustic nerve takes possession of the hindmost vertebra. I call it, therefore, 'ear-vertebra' (Ohrwirbel): and I regard this as the first cranial vertebra; the jaw-vertebra as the second, and the eye-vertebra as the third."—*ib.* p. 6.

After entering upon the difficulties which beset him in determining whether the petrosal belonged to the first (Ohrwirbel) or the second (Kieferwirbel), and enunciating his views on the essential relations of each cranial vertebra with a single special sense (excluding, however, smell and taste, as being inferior in dignity to the others), Oken proceeds, in his characteristic bold metaphorical language:—"Bones are the earthy hardened nervous system: Nerves are the spiritual soft osseous system—Continens et contentum."

"Between the sphenoid and occipital, between the sphenoid and petrosal, between the parietal (the temporal being removed) and the occipital, there runs a line which defines the anterior boundary of the first vertebra. In the line between the two sphenoids, or that which in man extends anterior to

* "Im August 1806 machte ich eine Reise über den Hartz,"—"ich rutschte an der Südseite durch den Wald herunter—und siehe da; es lag der schönste gebleichte Schädel einer Hirschkuh vor meinen Füssen. Aufgehoben, umgekehrt, angesehen, und es war geschehen. *Es ist eine Wirbelsäule*! fuhr es mir wie ein Blitz durch Mark und Bein—und seit dieser Zeit ist der Schädel eine Wirbelsäule."—Isis, 1818, p. 511.

† Uber die Bedeutung der Schädelknochen, 4to, 1807. I am indebted to my friend Mr. Tulk, the able translator of 'Wagner's Comparative Anatomy,' for the opportunity of perusing this most suggestive and original essay, which does not exist in either the Library of the British Museum, that of the College of Surgeons, or that of the Medico-Chirurgical Society. Mr. Tulk is at present engaged in the arduous task of translating the "Lehrbuch der Natur-philosophie" of Oken for the 'Ray Society.'

the pterygoid processes laterally and upwards through the fissura orbitalis superior, anterior to the great ala, and finally between the frontal and the parietal bones, we trace another line, which divides the second from the third vertebra" (*ib.* p. 7).

"Now," says Oken, "take the ear-vertebra from a fœtus of any mammal or of man, place near it an immature dorsal vertebra, or the third cervical of a crocodile, and compare the pieces of which they consist, their form, their contents, and the outlets for the nerves.

"According to Albinus and all anthropotomists, each vertebra of the fœtus consists of three distinct parts—the body and the two neurapophyses (bogentheile). You have the same in the occipital bone, but more clearly and more distinctly: the 'pars basilaris' is separated as the body of the vertebra from the 'partes condyloideæ,' which form the lateral parts: these are still more distinct from the 'pars occipitalis' which forms the spinous process: even this part is often bifid, like the spinous processes in *spina bifida*."

"Since then the foramen magnum is the hinder or lower opening of a vertebral canal, the condyles true oblique vertebral processes, the foramen lacerum an intervertebral foramen, and the crista occipitalis a spinous process, proved to be such by both its position and the muscles inserted into it,—since lastly the whole occipital bone in relation to its form as well as its function—inclosing the cerebellum as a production of the spinal chord,—is a true and in every sense characteristic vertebra, it is unnecessary to dwell more diffusely on parts, the bare mention of which suffices to make their nature recognizable."—*ib.* p. 7.

This will serve as an example of the close observation of facts, the philosophical appreciation of their relations and analogies, and, in a word, of the spirit in which Oken determines the vertebral relations of the cranial bones of the skull: and I refer to TABLE II. for his conclusions as to the parts of the second and third cranial vertebræ.

Reverting to the petrosal, Oken thus beautifully and clearly enunciates its essential nature and homology:—"You will say I have forgotten the 'pars petrosa.' No! It seems not to belong to a vertebra, as such; but to be a 'sense-organ' (Sinnorgan), in which the vertebral- or ear-nerve loses itself; and, therefore, is as distinct an organ from a vertebral element as is any other viscus (Eingeweide), or as is the eyeball itself. The (cause of) delusion (as to the homology of the petrosal) lies in this, viz. that it must be ossified agreeably with its nature (wesen), just as the eye must be crystallized."

Although Oken does not in this essay formally admit a fourth vertebra anterior to the 'eye-vertebra,' he recognises the vertebral structure as being carried out rudimentally or evanescently, by the vomer, as the prolongation of the cranio-vertebral bodies, by the lacrymal bones, as their neurapophyses, and by the nasal bones, as the spinous process. His ideas of a vertebra have evidently at this period not extended beyond the ordinary anthropotomical one of centrum and neural arch with its transverse, oblique, and spinous processes. When he indicates (beautifully and truly) the general homology of the palatine bones, as pleurapophyses, under the name of anchylosed or immoveable ribs of the head, it has reference to the transcendental idea of the repetition in the head of all the parts of the body. Thus the squamosal in mammals and the tympanic in birds represent the 'scapula' of the head, and at the same time, also, the ilium. The homologue of the squamosal (fig. 21, 27) in the bird is the 'humerus capitis': the malar (26) and the maxillary (21) are the 'oberarm' (radius and ulna capitis): the premaxillary (22) is the 'manus capitis.' The segments of the hind limb are

represented by divisions of the compound lower jaw in the crocodile and embryo bird (see TABLE, No. III.). The pterygoids (24), the essential distinction of which from the sphenoid Oken clearly recognises, are his 'clavículæ capitis.' Oken hints at, without accepting, the (serial) homology of the hyoid arch with the pelvis; but he regards the stylohyal (33) as the 'sacrum capitis' (*ib.* p. 16).

The year after the publication of Oken's famous 'Introductory Lecture,' Prof. Duméril, apparently unacquainted with its existence, communicated to the French Institute a memoir entitled 'Considérations générales sur l'analogie qui existe entre tous les os et les muscles du tronc dans les animaux,' the second paragraph of which is headed "De la tête considérée comme une vertèbre, de ses muscles et de ses mouvements." In this paragraph, repeating the homological correspondences, demonstrated by Oken, between the basioccipital as a vertebral centrum, the condyles as 'oblique processes,' and the occipital protuberance as a spinous process, he adds, that the mastoid processes are entirely conformable to transverse processes. And M. Duméril has, I believe, here the merit of having first enunciated the general homology of the mastoids, although he does not aim at showing to which vertebral segment of the skull they properly belong. Nor, indeed, with the exception of an observation that "very often the body of the sphenoid, like the 'apophyse basilaire' of the occiput, resembles the body of a vertebra," does he push the transcendental comparisons further. Geoffroy St. Hilaire tells us*, that even the moderate and very obvious illustrations of the general homologies of the cranial bones, which M. Duméril deduced from the anatomy of the occiput, excited an unfavourable sensation in the bosom of the 'Académie;' and that the phrase 'vertèbre pensante,' which a facetious member proposed as an equivalent for the word 'skull,' and which circulated, not without some risibility, along the benches of the learned during the reading of the memoir, reaching the ears of the ingenious author, the dread of ridicule checked his further progress in the path to the higher generalizations of his science, and even induced him to modify considerably many of the (doubtless happy) original expressions and statements in the printed report, so as to adapt it more to the conventional anatomical ideas of his colleagues.

As the truth of Oken's generalization began to be appreciated, it was remembered, as is usually the case, that something like it had occurred before to others. Autenrieth and Jean-Pierre Frank had alluded, in a general way, to the analogy between the skull and the vertebral column: Ulrich, reproducing, formally, Oken's more matured opinions on the cranial vertebræ, says, "Kielmeyerum præceptorem pie venerandum quamvis vertebram tanquam caput integrum considerari posse in scholis anatomicis docentem audivi." And the essential idea was doubtless present to Kielmeyer's mind, though he reversed M. Duméril's proposition, and, instead of calling the skull a vertebra, he said each vertebra might be called a skull. But these anticipations detract nothing from the merit of the first definite proposition of the theory. It would rather be an argument against its truth, if some approximative idea had not suggested itself to other observers of nature, who only lost the merit of developing it, from not appreciating its full importance. He, however, becomes the true discoverer who establishes the truth: and the sign of the proof is the general acceptance. Whoever, therefore, resumes the investigation of a neglected or repudiated doctrine, elicits its true demonstrations, and discovers and explains the nature of the errors that have led to its tacit

* Annales des Sciences Naturelles, t. iii. 1824, p. 177.

or declared rejection, may calmly and confidently await the acknowledgments of his rights in the discovery.

It has been unfortunate for Oken, that, with one exception—the gifted Bojanus—his successors in the development of the vertebral theory of the skull have hitherto exaggerated rather than retrenched the errors of their guide. Spix* lends an almost servile aid to Oken in endowing the artist's symbol of the cherub with all that it seems most to want, a thorax, abdomen and pelvis, arms, legs, hands and feet. He adopts Oken's original number and composition of the cranial vertebræ, and gives them new names, which being dissociated from Oken's peculiar idea of the essential subserviency of the cranial segments to certain organs of sense, are likely to be retained.

Bojanus† seems first to have determined the true elements of the neural arch of the nasal vertebra; and was as happy in perceiving the pleurapophysial relations of the tympanic pedicle, as Oken had been in reference to the palatine bone. He was less accurate in his idea of the vertebra to which it belonged. The analysis of Bojanus' craniovertebral system given in Table III. precludes the necessity of dwelling upon it in the brief historical sketch here attempted.

The modifications of his original idea which Oken has introduced into his edition of the 'Natur-philosophie' of 1843, bring it into close accordance with that of Bojanus, excepting that Oken conceives the cranial neurapophyses to answer also to ribs:—"An den Seiten eines jeden Körpers liegen Flügelfortsätze, welche den Querfortsätzen der Halswirbel oder den Rippen entsprechen: 'die Gelenkköpfe des Hinterhauptsbeins' (exoccipitals), 'die grossen' (ali-) 'und kleinen Flügel' (orbito-sphenoids), 'und die beiden Seiten des Siebbeins' (prefrontals)," p. 304. With regard to the facial bones of the skull, Oken still includes the explanation of their general homology in his original idea, that "the head is (a repetition of) the whole trunk with all its systems. . . . . The encephalon is the myelon (rückenmark); the cranium, the vertebral column; the mouth is intestine and abdomen; the nose, lungs and thorax; and the jaws, limbs (glieder)."—*Op. cit.* p. 300. An idea which vitiated his original essay, and which has had the effect of obscuring a great truth in nature in the smoke of a sacrifice to a false system.

This seems the place to notice a virtual testimony to the general accuracy of the Okenian cranial system, published in 1816 by the present eminent osteologist who holds the chair of Comparative Anatomy in the 'Jardin des Plantes.' In a note to his 'Prodrome d'une Nouvelle Distribution Systématique du Règne Animal,' published in the 'Bulletin des Sciences par la Société Philomathique,' 1816, p. 105, M. de Blainville says, "J'essayerai de montrer (!) que la tête dans les animaux vertébrés est composée, 1° d'une suite d'articulations ou de vertèbres soudées, chacune développée proportionnellement au système nerveux particulier qu'elle renferme, comme dans le reste de la colonne vertébrale; 2°, d'autant d'appendices paires qu'il y a de ces fausses vertèbres, et pouvant avoir des usages différens" (p. 108). M. de Blainville does not (like Bojanus) expressly mention the general homology of any of these appendages to the ribs, or parial appendages of the true vertebræ; but he leaves it to be so understood by his subsequent enumeration and classification of the 'appendices paires ou symmétriques,' which he describes as being always in relation with a vertebra or median piece. He says, *e. g.* "Ils peuvent être divisés en simples ou en composés, ou peut-être d'après leurs usages. Les appendices simples sont les côtes. Les appendices composés sont les membres, les mâchoires, les appareils des organes des

* Cephalogenesis, fol. 1815.

† Isis, 1818, and 'Parergon' in the 'Anatome Testudinis Europææ,' fol. 1821.

sens, le styloïde, les branches de l'hyoïde, qui sont ordinairement formés d'un plus ou moins grand nombre de pièces placées bout à bout. Quelquefois ces appendices sont libres à leur extrémité, d'autres fois ils se réunissent dans la ligne médiane inférieure en entr'elles, ou au moyen d'une pièce médiane, qu'on peut comparée, jusqu'à un certain point, au corps des vertèbres; d'ou il résulte ce qu'on nomme 'sternum' dans les mammifères, appareil branchial des poissons, hyoïde, sternum des oiseaux," etc. (*ib.* 1817, p. 110). Reserving the consideration of some of these propositions for a subsequent part of the present Report, I shall only notice, *en passant*, the complete concordance between these views of the general homology of the locomotive members with those which Oken expresses with his usual aphoristic brevity:—"Freye Bewegungsorgane können nichts anderes als frey gewordene Rippen seyn."

Cuvier includes amongst the general characters of the class *Mammalia* the arrangement of their cranial bones into three annular segments, corresponding essentially with those of which Oken had demonstrated the vertebral relations. "Leur crâne se subdivise comme en trois ceintures formées; l'antérieure, par les deux frontaux et l'ethmoïde; l'intermédiaire, par les pariétaux et le sphénoïde; la postérieure, par l'occipital: entre l'occipital les pariétaux et le sphénoïde, sont intercalés les temporaux, dont une partie appartient proprement à la face*."

What M. de Blainville (1816) pledges his efforts to demonstrate, Oken (Isis, 1817) was exulting in the reception of, 'not only in Germany but all Europe.' "Seit Erscheinung dieser Schrift und nun 10 Jahre verflossen.—Man spricht nun von Kopfwirbeln, Kopfarmen und Füssen, von Bedeutung der einzelnen Skeletknochen wie von einer uralten Sache; die schon in der Bibel und den Propheten gestanden," p. 1204. The chief differences, as compared with Oken's definition, are, that Cuvier, finding the frontal arch to rest upon both ethmoïd and presphenoid, assigns to the former bone the completion of the anterior cranial cincture below; and completes, in like manner, the parietal cincture by the sphenoid in its anthropotomical sense, making no distinction between the anterior and the posterior divisions of the bone. Cuvier does not apply this principle of arrangement of the cranial bones to the skull of the lower classes of vertebrata (in which, nevertheless, it is more clearly manifested than in mammals): in generalising on the constitution of the vertebrate skull, he classifies the bones, after the anthropotomists, into 'those of the cranium which encompass the brain, and those of the face, which consist of the two jaws and the receptacles of the organs of sense.'† With regard to the skull of fishes, in which Bojanus had found so clear an illustration and confirmation of the Okenian views, Cuvier merely says, it is almost always divisible into the same number of bones as that of other ovipara. The frontal is composed of six pieces; the parietal of three; the occipital of five; five of the pieces of the sphenoid and two of each of the temporals remain in the composition of the cranium‡.

In his great works the 'Histoire des Poissons' and the 'Leçons d'Anatomie Comparée,' posthumous edition, he expresses more decidedly his objections to the views of the segmental or vertebral structure of the skull.

Göthe, in a small fasciculus of 'Essays of Comparative Anatomy,' which he published in the year 1820, entitles the 8th, "Can the bones of the skull

* Règne Animal, 8vo, 1817, t. i. p. 62.

† "La tête est formée du crâne, qui renferme le cerveau, et de la face, qui se compose des deux mâchoires et des receptacles des organes des sens."—Règne Animal, i. ed. 1817, p. 62; ed. 1829, p. 52.

‡ *l. c.* ii. (1817), p. 107; (1829), p. 125.

be deduced from those of the vertebral column, and thence receive an explanation of their forms and functions?" He states that the idea of the three facial vertebræ occurred to him in the year 1790, prior to which time he says "die drei hintersten erkennt ich bald." The idea is developed in his essay as follows:—"The skull of mammalia is composed of six vertebræ; three for the hinder division inclosing the cerebral treasure; three composing the fore part which opens in presence of the exterior world, which it seizes and introduces.

"The first three vertebræ are admitted (he alludes to Oken and Spix): they are,—

"The occipital.

"The posterior sphenoid.

"The anterior sphenoid.

"The three others are not yet admitted; they are,—

"The palatine bone.

"The upper maxillary.

"The intermaxillary.

"If some of the eminent men who ardently cultivate this subject should feel interested by this simple enunciation of the problem, and would illustrate it by some figures indicating by signs and ciphers the mutual relations and secret affinities of the bones, its publication would strongly draw the thinking mind in that direction, and we may, perhaps, one day, ourselves give some notes on the mode of considering and treating these questions."

Professor Carus of Dresden has best responded to this appeal of his immortal countryman: but it must be admitted that the detailed and complex exposition of the theory of the six vertebræ and intervertebræ, of which the general results are given in Table III., have yielded to anatomical science a result which is hardly equivalent to the zeal and pains manifested in the attempt, or to the artistic merit of the illustrations, published by the accomplished author of the 'Urtheilen des Knochen und Schalengerüstes' (fol. 1828).

Geoffroy St. Hilaire deems the skeleton of the head to be composed of seven vertebræ; and he has the merit of having more steadily sought the homologies of the inferior arches of the cranial vertebræ than his predecessors, who seem not to have sufficiently appreciated the essential character of these portions of the primary segments of the vertebrate endo-skeleton. Nevertheless it must be admitted that Cuvier has made good the grounds of his rejection of Geoffroy's theory, as one based less on observation than on purely *à priori* views, according to which the bones of the skull, real or imaginary, are arranged into seven vertebræ, composed of nine pieces each*. The cranio-vertebral system of Geoffroy is liable to the further objection, that he has combined, as in the case of his typical vertebra from the tail of the flounder, parts of the exo-skeleton (*e. g.* the suborbitals) with parts of the endo-skeleton to which alone the vertebral theory is applicable.

In the fasciculi of the magnificent 'Ostéographie' with which Professor de Blainville has enriched his science, the descriptions follow the plan of the classification of the bones of the skeleton propounded in the above-cited Memoirs in the 'Bulletin des Sciences' for 1816 and 1817. In the Prospectus of the 'Ostéographie', M. de Blainville briefly refers to the great questions of comparative anatomy, which the German organologists have comprehended under the name of '*Signification of the Skeleton*,' in allusion only to the "gross errors and opinions almost extravagant, of some of the persons who have occupied themselves with these questions:" whilst he reprobates, on the

* Cuvier, Histoire des Poissons, 4to, t. i. p. 230.

other hand, in equally general terms, "those who have been unable to elevate themselves to these kind of questions, partly on account of the nature of their minds, partly from the want of proper and sufficient subjects of contemplation*."

Neither the first step, the most difficult of all, nor any of the succeeding steps in the acquisition of such views of the 'Signification of the Skeleton' as M. de Blainville adopts are noticed: no objection to the vertebral system of the skull is answered: no error that may have opposed itself to a reception of the doctrine is explained or refuted: of the particular labours and discoveries of individual homologists the author of the 'Ostéographie' is silent. He defines a vertebra, in the language of anthropotomy, as a single bone:—"Une vertèbre, considérée d'une manière générale, et par conséquent dans son état complet, est un os court, médian, symmétrique, formant un corps, partie principale de la vertèbre, aux deux faces opposées de laquelle, externe ou dorsale, interne ou ventrale, s'applique un arc plus ou moins développé, d'ou résultent deux canaux, l'un au dos, l'autre au ventre." (*ib.* fasc. i. p. 6.) We discern the influence of the ideas of his ingenious contemporary, Geoffroy St. Hilaire, in the admission of the ventral or inferior, as well as the dorsal or superior arch; and, like Geoffroy, he recognises the physiological relation of the upper arch to the protection of the nervous system, and that of the lower arch to the protection of the vascular system: but, overlooking or rejecting the idea of the relation of the ribs as the inferior protecting arches of the expanded central organ of the vascular system, he considers the ventral (hæmal) arches as arriving at their maximum of development in the tail. The dorsal and thoracic vertebræ are, accordingly, characterized as those which are provided with costiform appendages diversely articulated to them; overlooking, I may remark, the costal appendages of the cervical vertebræ in the saurians and those which become anchylosed to the cervical vertebræ in birds, as do, frequently, their serial homologues to the dorsal vertebræ in the same class. M. de Blainville seems, also, wholly ignorant of the fact that the bent-forward ends of the long transverse processes of the lumbar vertebræ of the hares, cavies, and many other rodents, are primarily developed as distinct costal rudiments: the same rudiments of lumbar ribs are found in the fœtus of the hog, and in the first lumbar vertebra of many mammals†. "Les lombaires," says M. de Blainville, "n'ont plus de côtes, même incomplètes."

The ribs not being regarded as essentially parts of the inferior or hæmal arches of vertebræ, the sternal bones which complete these greatly expanded arches are accordingly regarded as a distinct series of bones, and called 'sternebers.' M. de Blainville, as we have seen, had before (1817) compared them to vertebral bodies. In the 'Ostéographie,' however, he rightly regards the body of the hyoid as their serial homologue, but does not extend his comparison to the bones that in like manner complete the mandibular and maxillary arches. These, with the cornua of the hyoid, and the sternal and vertebral ribs, he classes with the bones of the extremities, under the name of appendages (appendices), adopting, in his larger work, as in his original essay, essentially the idea of Oken, that the locomotive members are liberated ribs.

After much additional research and comparison since the first publication of my ideas of the constitution of the typical vertebra or primary segment of the endo-skeleton‡, I have found no reason for modifying them, but have derived additional evidence of their accuracy; and I therefore reproduce the diagrammatic figure with which they were originally illustrated (fig. 14).

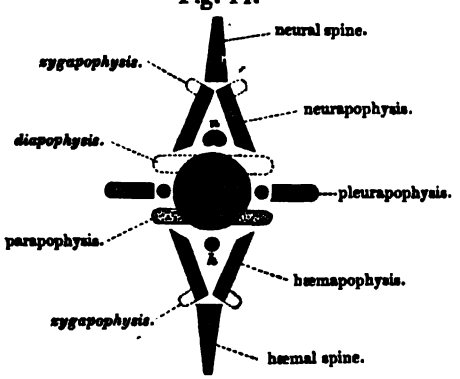
* Ostéographie, Prospectus, April, 1839, p. 5.
† Thiele, in Müller's Archiv für Physiologie, 1839, p. 106.
‡ Geological Transactions, 4to, 1838, p. 518.

Although my investigations of the fundamental type of the vertebrate skeleton were first made upon the class of fishes, where vegetative uniformity or irrelative repetition most prevails, and where, therefore, the type is least obscured by the modification of one part in mutual subserviency with another, I soon found that I should be led astray by confining my observations to fishes, and by borrowing my illustrations from that class. Comparison of the piscine skeleton with those of the higher animals demonstrates that the natural arrangement of the parts of the endoskeleton is in a series of segments succeeding each other in the axis of the body. These segments are not, indeed, composed of the same number of bones in any class or throughout any individual animal. But certain parts of each segment do maintain such constancy in their existence, relation, position, and offices, as to enforce the conviction that they are homologous parts, both in the constituent series of the same individual skeleton, and throughout the series of vertebrate animals. For each of these primary segments of the skeleton I retain the term 'vertebra'; but with as little reference to its primary signification, as a part specially adapted for rotatory motion, as when the comparative anatomist speaks of a sacral vertebra. The word may, however, seem to the anthropotomist to be used in a different or more extended sense than that in which it is usually understood; yet he is himself, unconsciously perhaps, in the habit of including in certain vertebræ of the human body, elements which he excludes from the idea in other natural segments of the same kind, influenced by differences of proportion and coalescence, which are the most variable characters of a bone. Thus the rib of a cervical vertebra is the 'processus transversus perforatus,' or the 'radix anticus processus transversi vertebræ colli'*: whilst in the chest, it is 'costa,' or 'pars ossea costæ.' But the ulna is still an ulna in the horse, although it be small and anchylosed to the radius.

The osteology of man, therefore, cannot be fully or rightly understood until the type of which it is a modification is known, and the first step to this knowledge is the determination of the vertebral segments, or natural groups of bones, of which the myelencephalous skeleton consists.

I define a vertebra, as *one of those segments of the endo-skeleton which constitute the axis of the body, and the protecting canals of the nervous and vascular trunks*: such a segment may also support *diverging appendages*. Exclusive of these, it consists, in its typical completeness, of the following elements and parts:—

Fig. 14.



Ideal typical vertebra.

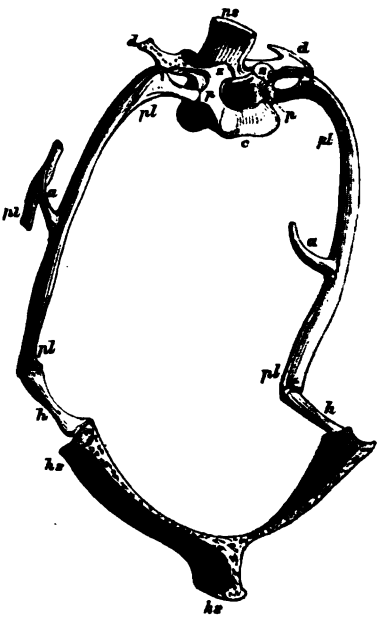
* Soemmerring, De Corporis Humani Fabricâ, 1794, i. p. 239.

The names printed in roman type signify those parts which, being usually developed from distinct and independent centres, I have termed 'autogenous' elements. The italics denote the parts, more properly called processes, which shoot out as continuations from some of the preceding elements, and are termed 'exogenous': *e.g.* the diapophyses or upper 'transverse processes,' and the zygapophyses, or the 'oblique' or 'articular processes' of human anatomy.

The autogenous processes generally circumscribe holes about the centrum, which, in the chain of vertebræ, form canals. The most constant and extensive canal is that (fig. 14, *n*) formed above the centrum, for the lodgment of the trunk of the nervous system (neural axis) by the parts thence termed 'neurapophyses.' The second canal (fig. 14, *h*), below the centrum, is in its entire extent more irregular and interrupted; it lodges the central organ and large trunks of the vascular system (hæmal axis), and is usually formed by the laminæ, thence termed 'hæmapophyses.' At the sides of the centrum, most commonly in the cervical region, a canal is circumscribed by the pleurapophysis or costal process, by the parapophysis, or lower transverse process, and by the diapophysis, or upper transverse process, which canal includes a vessel, and often also a nerve.

Thus a typical or perfect vertebra, with all its elements, presents four canals or perforations about a common centre; such a vertebra we find in the thorax of man and most of the higher classes of vertebrates, also in the neck of many birds. In the tails of most reptiles and mammals, the hæmapophyses (as in fig. 14) are articulated or anchylosed to the under part of the centrum; space being needed there only for the caudal artery and vein. But where the central organ of circulation is to be lodged, an expansion of the hæmal arch takes place, analogous to that which the neural arches of the cranial vertebræ present for the lodgment of the brain. Accordingly in the thorax, the pleurapophyses (fig. 15, *pl*) are much elongated, and the hæmapophyses (fig. 15, *h*) are removed from the centrum, and are articulated to the distal ends of the pleurapophyses; the bony hoop being completed by the intercalation of the hæmal spine (fig. 15, *hs*) between the ends of the hæmapophyses. And this spine is here sometimes as widely expanded (in the thorax of birds and chelonians, for example) as is the neural spine (parietal bone or bones) of the middle cranial vertebra in mammals. In both cases, also, it may be developed from two lateral halves, and a bony intermuscular crest may be extended from the mid-line, as in the skull of the hyæna, and the breast-bone of the bird (fig. 15, *hs*). To facilitate the comparison of the merits of the preceding view and nomenclature of the typical vertebra with those of other comparative anatomists, I have thrown the results into the form given in Table II.

Fig. 15



Natural typical vertebra: thorax of a bird.

To the question why I should have invented new names when Geoffroy St. Hilaire had already proposed others for the vertebral elements, I can only repeat the regret with which I found myself compelled to that invidious step, after having arrived at the conviction, that the learned Parisian Professor had sometimes applied the same term to two distinct elements, and sometimes two distinct names to one and the same element: and I am glad to be able to cite the authority of Cuvier for the propriety and advantage of such a step. His words are in reference to an analogous case, "Donner à un mot connu un sens nouveau est toujours un procédé dangereux, et, si l'on avoit besoin d'exprimer une idée nouvelle, il vaudroit encore mieux inventer un nouveau terme, que d'en détourner ainsi un ancien *." Now there is scarcely one term in the first column in Table II. which is synonymous with its opposite in the second column, or which expresses exactly the same idea; and the discrepancy becomes greater in regard to the terms applied to the vertebral elements of the head, in columns 1 and 5 of Table III. The respective concordance of the views of the vertebral archetype entertained by Geoffroy and myself with Nature will be determined and judged of by succeeding impartial and original observers.

With regard to the term *cycléal*, "de *κύκλος*, cercle, pour rappeler sa forme annulaire, permanentes chez les premiers," (Articulata, Dermovertebrés, Geoff.) "et, au contraire, non persévérante chez les derniers" (Vertebrata, Hauts-vertébrés, Geoff.), it is understood by its author to apply to the annular segment of the crust of the insect, as well as to the 'centrum' of the endoskeletal vertebra. Geoffroy's primary division of the parts of a vertebra is into the centre or nucleus (noyau) and the lateral branches. The upper 'branches laterales' or 'périaux' are equivalent to my neurapophyses and also to my neural spine, in fishes: the lower lateral branches or 'paraaux' are sometimes free and floating†, when they answer to my 'pleurapophyses'; but they are sometimes so united as to form a canal, when they answer to my 'parapophyses' in the tail of fishes ‡, and to my 'hæmapophyses' in the tail of cetaceans. Geoffroy supposed, for example, that the hæmal canal in the tail in all fishes was formed by the ribs, bent down and anchylosed at both ends§, and that the hæmal canal in the tail of the crocodile and whale was constituted by a like metamorphosis of the same vertebral elements. He, also, argued that, as the small spinal chord of fishes did not demand so great a development in breadth of the neurapophyses, they were permitted to attain to unusual length; and that, coalescing together, they thus constituted not only the neural arch but the neural spine, to which latter, therefore, he extended the name 'périal'; whilst to the corresponding part in mammals he gives the name of 'épial'. But, again, in fishes, he calls the dermal spines developed in the embryonic median fold of integument which is metamorphosed into the dorsal fins, 'épiaux'; and the corresponding dermal spines of the ventral fin 'cataaux.' The lepidosiren, however, manifests the neural spine distinct from both the neurapophyses below and the dermo-neural spine above: and such neural spine is unequivocally homologous with the anchylosed neural spine in osseous fishes ||. It is quite in harmony with the position of the class of fishes at the bottom of the vertebrate scale that they should present a greater degree of calcification of the parts belonging to the same category of the skeletal system as the shells and crusts of the invertebrates: hence it is that whilst the median dermal fins of the marine mammalia have

* Mémoires du Muséum, t. xx. p. 123.

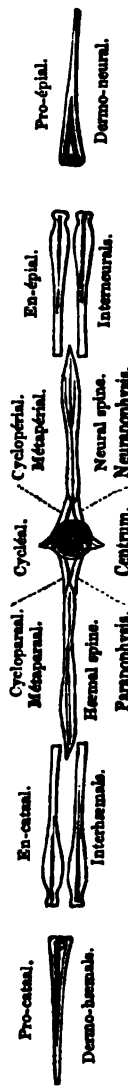
† As they are illustrated in the abdominal vertebra of the fish figured by Geoffroy in the 'Mémoires du Muséum,' t. ix. (1822), pl. 5, fig. 4, *o*. ‡ *Ib.* fig. 2, *o o*.

§ This occurs as an exceptional condition, in the lepidosteus, and perhaps in lepidosiren.

|| Linn. Trans. vol. xviii. p. 23, fig. 4, *c*, *d*.

their supporting skeleton in the primitive histological fibrous state, the corresponding parts are ossified in fishes: rarely, however, are such parts in answerable number to the vertebræ; and the true spines of these vertebræ, when the median fins and their bony spines are removed, in fishes, show as little indication of the place or existence of such fins, as do the vertebræ in the porpoise of the existence of its dermal fin. In proportion as ossification has extended into the dermal system of fishes it has been arrested in the vertebræ, which in the trunk and tail of fishes present their least complex condition. Two of the autogenous elements, the 'hæmapophyses,' are absent, and are commonly represented, in the tail, by the modified 'parapophyses.' The seeming complexity of a fish's vertebra arises from the intercalation of bones appertaining to the system of the dermo-skeleton: it would have been an unusual exception to the general course of development if the lowest of the vertebrate classes should have presented the vertebral skeleton in its highest state of complication; and Geoffroy St. Hilaire was unfortunate in taking a fish's vertebra with its extrinsic evertebrate complications, as the perfect type of that primary segment of the myelencephalous skeleton (fig. 16). He was still more unlucky in having for the subject of his figure* a specimen from which two of the pieces had been accidentally lost, as Cuvier afterwards pointed out; yet Geoffroy's mutilated caudal vertebra of the plaice continues to be copied in some compilations of comparative anatomy, as the type of a vertebra! To obtain the dermal spines (pro-epial and pro-cataal) of the vertically extended caudal vertebræ of fishes, Geoffroy had recourse to a hypothetical division lengthwise of the interneural and interhæmal spines (which are represented as being single in his figure), and to as gratuitous a displacement of one of the halves from the side to the summit of the other†. Now the interneural and interhæmal spines are actually double in relation to the neural and hæmal spines; yet they coexist with a dermo-neural and dermohæmal ray, which therefore needs no imaginary change of place of either of its supporting spines to account for its existence. I subjoin in fig. 16 an entire vertebra answering to the mutilated one figured by Geoffroy; and for the better understanding of the difference between his determinations of the vertebral elements and those given in the present Report, the names respectively indicating those different determinations are added to the figure. In the description of the plate in the 'Mémoires du Muséum,' Geoffroy explains that the 'pro-épial' is the left half or 'épial *gauche*,' and the en-épial the right half or 'épial *droit*': that the en-cataal is the right half or 'cataal *droit*,' and the pro-cataal the left half or 'cataal *gauche*,' of his imaginarily divided epivertebral and catavertebral elements (*l. c.* p. 115).

Fig. 16.



Endo- and exo-skeletal elements of a caudal vertebra of a Plaice (*Pleuronectes*).

* Mémoires du Muséum, t. ix. (1822), pl. 5, fig. 1.

† "L'une de ces pièces monte sur l'autre"—"l'une se maintient en dedans, quand l'autre s'élance en dehors," *ib.* p. 97.

The trunk of fishes, in respect of its viscera and the degree of development of the endoskeleton, answers to the lumbar and caudal regions of air-breathing vertebrates, where the vertebræ usually lose some of their elements, at least as bones. The heart and respiratory organs are placed in the head of the fish; and it is only in this region that the vertebral segments attain to typical completeness in that class. Geoffroy, in studying the special and general homologies of the bones of the head of fishes, blends indiscriminately, as in the supposed typical vertebra from the tail, elements of the dermoskeleton (suborbitals and lacrymals, *e. g.*) with those of the endoskeleton; and also presses the capsules of the special organs of sense into the composition of the seven cranial vertebræ of his system. It needs only to compare the synonyms of the elements of these vertebræ in Table III. to perceive how impossible it would have been to have expressed the ideas which I wish to expound and illustrate in this Report by the use of the names for the vertebral elements proposed by Geoffroy, or of English equivalents. The prefrontals, *e. g.* (no. 14), which I regard as the neurapophyses of the nasal vertebra, are, according to Geoffroy, epials of the 2nd or labial vertebra in the class of fishes; but are epials of the 1st or nasal vertebra in the crocodile, according to the tables given in the 'Annales des Sciences,' t. iii. pl. 9, and 'Atlas,' p. 44; whilst they are the perials of the 2nd vertebra in the scheme of 1825, cited in the fifth column of Table III.

I have deemed it requisite to enter the more fully into the grounds for abandoning the analysis and nomenclature of the typical vertebra proposed by Geoffroy, because they have received the sanction in this country of the learned Professor of Comparative Anatomy at University College. Dr. Grant* converts the French names into English equivalent phrases; 'cyclo-vertebral element' for *cycléal*, 'perivertebral element' for *périal*, &c.; and abandons the advantage of a definite name, without remedying the disadvantages of the double employment of the same names for two distinct elements, and of the application of different phrases for the same element. If, for example, the neural spine of the reptile or mammal be, in nature, the homologue of the neural spine of the fish, then the latter is called an 'epivertebral element,' whilst the former is called a 'perivertebral element.' If the dermo-neural spines of the dorsal fin of a fish be, in nature, homologous with the fibro-ligamentous tissue supporting the dorsal fin of the dolphin, then the term 'epivertebral element' is applied to a spine of the exoskeleton in the fish, and to a spine of the endoskeleton in the mammal, which spine co-exists with such dermal spine in the fish (see fig. 16). If the parapophysis or inferior transverse process in the fish be a distinct element from the diapophysis or superior transverse process in the mammal, the same phrase, 'paravertebral element,' is applied to each. Dr. Grant, moreover, gives the same name, 'catavertebral elements,' to the free vertebral ribs in fig. 28, B. *g.* p. 58, *op. cit.*, as he applies to the hæmapophyses in the tail of the reptile or cetacean, in fig. 28, C. *g. loc. cit.*; whilst Geoffroy applies the name 'cataaux' to the sternal ribs, and not to the vertebral ribs: and it is precisely with the sternal ribs that the chevron bones in the tails of reptiles and cetaceans are homologous, and both are, therefore, the 'hæmapophyses' in my system. The transference of the term 'catavertebral elements' (for *cataaux*), from the 'côtes sternales' to the pair of ribs extended from the ends of the parapophyses of the abdomen of fishes, is a deviation from the original vertebral system of Geoffroy, which seems to lead further away from nature. If it is meant that the outstretched parapophyses in the diagram of the abdominal vertebra of a fish (fig. 28, B. *f. f. loc. cit.*), and which are there called 'paravertebral elements,' are the homo-

* Outlines of Comparative Anatomy, 1835, pp. 57–59.

logues of the 'côtes vertébrales' of higher vertebrates, to which Geoffroy assigned the name 'paraaux,' this appears to be another misapprehension of the relations in question.

Development of vertebræ.—Before applying the idea of the archetypal vertebra, or primary segment of the endo-skeleton, given in figs. 14 and 15, to the elucidation of the modifications of those segments in the different vertebrate classes, I shall premise a few observations on the mode of development of the vertebræ in those classes.

The chief condition of the development of distinct vertebræ in the trunk is the conjunction of nerves with, or their progress from the spinal chord: at least, this circumstance, with the concomitant exit of blood-vessels from the neural canal, seems to determine the development of the neurapophyses: and the vertebral bodies are not slow in coinciding in number with those important arches; and in determining with the regular primary pairs of (intercostal, lumbar, &c.) arteries, the inferior or hæmal arches. We may learn how much the development of the neurapophyses and vertebral bodies depends, in the trunk, upon the conjunction of nerves with the spinal chord, by the fact that, in the regenerated tails of lizards, the vertebral axis remains continuous and unjointed, because there is no co-extensive spinal chord giving off pairs of nerves.

An extremely delicate fibrous band, with successively accumulated gelatinous cells, compacted in the form of a cylindrical column, and inclosed by a membranous sheath, is the primitive basis, called 'notochord'* (*chorda dorsalis* seu *gelatinosa*, Lat., *gallertsäule* und *ruckensaite*, Germ.), in and around which are developed the cartilaginous or osseous elements by which the vertebral column is established in every class of *Myelencephala*.

The earlier stages of vertebral development are permanently represented, with individual peculiarities superinduced, in the lower forms of the class of fishes†. In the *Dermopteri* or cyclostomous fishes, the neural and hæmal canals are formed by a separation of the layers of the outer part of the aponeurotic sheath of the gelatinous chorda: in the lancelet (*Amphioxus*) there is no distinction of structure in the cranial part supporting the anterior end of the neural axis, with which the trigeminal, optic and olfactory nerves communicate, and the rest of the rudimental vertebral column: a labial cartilaginous arch supporting the tentacula is, at least, the only lineament of development which sketches out the skull. In the myxinoids the skull includes a complex system of cartilages, but the vertebral column of the trunk has not advanced beyond the gelatino-aponeurotic stage. In the lamprey cartilaginous laminæ are developed in the outer layer of the fibrous sheath, and give the first indication of neural arches‡. In the sturgeons (*Sturio*, *Polyodon*) the inner layer of the fibrous capsule of the gelatinous notochord has increased in thickness, and assumed the texture of tough hyaline cartilage. In the outer layer are developed distinct, firm, and opake cartilages, the neurapophyses, which consist of two superimposed pieces on each side, the basal portion bounding the neural canal, the apical portion the parallel canal filled by fibrous elastic ligament and adipose tissue; above this is the single cartilaginous neural spine. The parapophyses are now distinctly developed, and joined together by a continuous expanded base, forming an inverted arch beneath the notochord for the vascular trunks, even in the abdomen. Pleurapophyses are articulated by ligament to the ends of the

* Νῶτος *back*, χορδή, *string*. We have hitherto had no English equivalent for this embryonic keel or basis of every vertebrate animal: 'dorsal chord' or 'chorda' is liable to [illegible] for the 'spinal chord.'

[illegible]es on Vertebrata, 1846, pp. 45, 46.

[illegible] Muséum d'Histoire Naturelle, t. i. 1815, p. 130.

laterally projecting parapophyses in the first twelve or twenty abdominal vertebræ: in the anterior ones these 'vertebral ribs' are composed of two or three distinct cartilages*: the posterior pleurapophyses are short and simple. The parapophyses gradually bend down to form hæmal arches in the tail, at the end of which we find hæmal cartilaginous spines corresponding to the neural spines above. The tapering anterior end of the notochord is continued forwards into the basal elements of the cranial vertebræ. Vegetative repetition of perivertebral parts not only manifests itself in the composite neurapophyses and pleurapophyses, but in a small accessory (interneural) cartilage, at the fore and back part of the base of the neurapophysis; and by a similar (interhæmal) one at the fore and back part of most of the parapophyses†.

Amongst the sharks (*Squalidæ*) a beautiful progression in the further development of a vertebra has been traced out, chiefly by J. Müller‡. In *Heptanchus* (*Squalus cinereus*) the vertebral centres are feebly and vegetatively marked out by numerous slender rings of hard cartilage in the notochordal capsule, the number of vertebræ being more definitively indicated by the neurapophyses and parapophyses; but these remain cartilaginous. In the piked dog-fish (*Acanthias*) and the spotted dog-fish (*Scyllium*) the vertebral centres coincide in number with the neural arches, and are defined by a thin layer of bone, which forms the conical articular cavity at each end: the whole exterior of the centrum is covered by soft cartilage, except at the concave ends; the two thin funnel-shaped plates of osseous matter coalesce at their perforated apices, and form a basis of the vertebral body like an hour-glass; the series of these centrums protecting a continuous moniliform remnant of the gelatinous notochord. In the great basking-shark (*Selache*) the vertebral bodies are chiefly established by the terminal bony cones, the thick margins of which give attachment to the elastic capsules containing the gelatinous fluid, which now tensely fills the intervertebral biconical spaces. Four sub-compressed conical cavities extend, two from the bases of the neurapophyses, and two from those of the parapophyses, towards the centre of the vertebral body, contracting as they penetrate it. These cavities always remain filled by a clear cartilage: the central two-thirds of the rest of the vertebral body contain concentric, progressively decreasing, and minutely perforated rings or cylinders of bone, interrupted by the four depressions: the peripheral third of the vertebral body contains longitudinal bony laminæ, which radiate, perpendicularly to the plane of the outermost cylinder, to the circumference; these outer laminæ lie, therefore, parallel with the axis of the vertebra, and the intervening fissures, like those between the concentric cylinders within, are filled by clear cartilage, which shrinks, and leaves them open in the dry vertebra§.

In *Cestracion*, the intermediate part of the centrum between the terminal cones is strengthened by longitudinal radiating plates only; in *Squatina* by concentric cylinders only. In the tope (*Galeus*) all the space between the terminal bony cones is ossified, except the four conical cavities, the bases of which are closed by the neur- and par-apophyses; so that the whole exterior of the centrum appears formed by smooth compact bone.

In the osseous fishes I find that the centrum is usually ossified from six points, four of which commence, as Rathke‖ describes, in the bases of the

* Brandt & Ratzeburg, Medizinische Zoologie, 4to, 1833, t. ii. pl. iv. fig. 1.
† Hunterian Lectures on Vertebrata, 1846, p. 53, fig. 12.
‡ See Agassiz, Recherches sur les Poiss. Foss. t. iii. pp. 361, 369.
§ Hunterian Lectures on Vertebrata, 1836, p. 55, fig. 13.
‖ Abhandlungen zur Bildungs und Entwickelungsgeschichte, Zweiter Theil, 1833, p. 41.

two neurapophyses and the two parapophyses; but the terminal concave plates of the centrum are separately ossified. They coalesce with the intermediate part of the centrum, which is sometimes completely ossified, but commonly a communicating aperture is left between the two terminal cones; and in many cases, the plates by which calcification attains the periphery of the body leave interspaces permanently occupied by cartilage, forming cavities in the dried vertebra, especially at their under part, or giving a reticulate surface to the sides of the centrum. The expanded bases of the neur- and par-apophyses usually soon become confluent with the bony centrum; sometimes first expanding so as wholly to inclose it, as, for example, in the tunny, where the line of demarcation may always be seen at the border of the articular concavity, though it is quite obliterated at the centre, as a section through that part demonstrates.

Müller correctly distinguishes a 'central' from a 'peripheral' (cortical) part or seat of the ossification of the vertebral bodies of fishes. The peripheral ossification which takes its rise from the outer layer of the fibrous sheath of the notochord sometimes extends into broad plates beneath the anterior vertebræ of the trunk, and tends to fix or anchylose a certain number of them; when they are commonly represented by the partially distinct central parts of the bodies, together with the neur- and par- and pleur-apophyses.

The batrachia follow closely the stages above-cited in fishes; the centrums being arrested at the biconical stage in the perennibranchiates, but converted into ball-and-socket vertebræ by the ossification of the interposed gelatinous ball* and its adhesion, either to the fore-part of the centrum (*Pipa*, *Salamandra*), or the back part (*Rana*, *Bufo*). The mode of ossification of the centrum varies somewhat in batrachia. Müller† describes annular ossifications in the sheath of the notochord of the *Rana temporaria* and *R. esculenta*, which support, at first, the neurapophyses. Dugés, apparently influenced by M. Serres' so-called 'law of centripetal development,' describes two cartilaginous nuclei, side by side; but the more obvious and better-determined development of the vertebræ of fishes gives no countenance to this bilateral beginning of ossification of the centrum as a general law. The first distinct bony nucleus in the centrum observed by Dugés was bilobed, and afterwards cubical; but excavated before and behind, as well as beneath‡. The ossification of the centrum is completed by an extension of bone from the bases of the neurapophyses, which effect, also, the coalescence of these with the centrum. In *Pelobates fuscus*, and *Pelobates cultripes*, Müller found the entire centrum ossified from this source, without any independent points of ossification.

The vertebræ of the tail of the larvæ of the anourans are represented distinctly only in the aponeurotic stage. Even when the change to cartilage takes place, the tendency to coalescence has begun to operate, and only two long neurapophyses are established on each side: the ossification of these plates extends into the fibrous sheath of the remnant of the coccygeal notochord, and they coalesce when the perishable parts of the tadpole-tail have been absorbed, and the fore- and hind-legs developed, constituting the long, often hollow, and inferiorly grooved coccygeal bony style.

In saurians, birds and mammals, the notochord is inclosed by cartilage before ossification begins; which cartilage is continuous with the cartilaginous neurapophyses§. In birds, the two histological processes, chondrifica-

* Dutrochet, Mémoires pour servir à l'Histoire Nat. et Physiol. des Animaux, &c., t. ii. p. 302. 1837.

† Neurologie der Myxinoiden, 1840, p. 69.

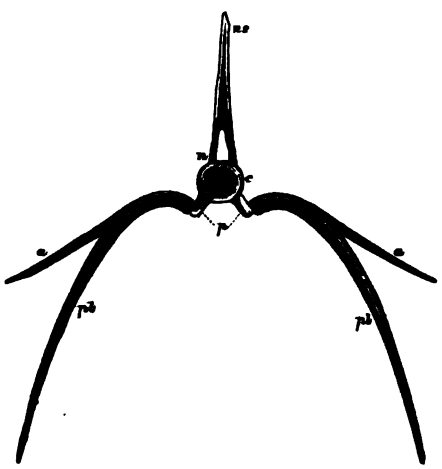
‡ Recherches sur les Batraciens, 1835, 4to, p. 106.

§ Müller, Vergleichende Anatomie der Myxinoiden, Neurologie, 1840, p. 74.

tion and ossification, do not precisely follow the same route. In the centrums of the dorsal and cervical vertebræ of the chick chondrification is centripetal: it begins from two points at the sides and proceeds inwards, the middle line of the under surface of the primitive notochord resisting the change longest. But, when the lateral cartilages have here coalesced, ossification begins at the middle line and diverges laterally; the primitive nuclei of the bony centres appearing as bilobed ossicles, and its direction is centrifugal. The lobes ascend to embrace the shrivelled remnant of the chorda, like the hollow vertebral centres in fishes. Only in the sacral vertebræ has ossification been seen to begin from two distinct points at the middle line. The bases of the separately ossifying neurapophyses extend over much of the centrum, and soon coalesce with it. In reptiles a greater proportion of the centrum is ossified from an independent point, and the bases of the neurapophyses often remain permanently distinct and united to the centrum by suture. In mammals, as in fishes, the centrum is ossified from an anterior and posterior centre, establishing the articular surfaces, as well as from an intermediate point. This is considerably overlapped by the bases of the neurapophyses, before they coalesce with the centrum. The three primitive parts of the centrum remain longest distinct in the cetacea. The body of the human atlas is sometimes ossified from two, rarely from three, distinct centres placed side by side *. From these ascertained diversities in the mode of formation of the central element of the vertebra, it will be seen how little developmental characters can be relied on as affecting the determination of homologous parts.

General Characters of Vertebræ of the Trunk.—The ossified parts of the abdominal vertebræ of osseous fishes answer to *c*, centrum; *n*, neurapophyses; *n s*, neural spine; *p*, parapophyses; *pl*, pleurapophyses; and *a*, appendages (fig. 17).

Fig. 17.



Ossified parts of abdominal vertebra, Fish.

The neurapophyses commonly coalesce with their respective centrums; except in the case of the atlas, where the neural arch is sometimes quite separated from the centrum, and wedged between those of the occiput and second vertebra. I have found also the neurapophyses of the two last caudal vertebræ unanchylosed to their centrums in a large sea-perch (*Centropristis gigas*, O.) in which the five terminal hæmal arches and spines remained similarly distinct, and articulated with the centrums below. In the carp and pike, the primitive independence of both neurapophyses and parapophyses is more general and longer maintained. In the lepidosiren the vertebral bodies are not developed, the notochord being persistent; but the peripheral vertebral elements are well-ossified: the neurapophyses in this fish remain distinct from the neural spines; and the hæmal spines are in like manner moveably articulated to the hæmal arches. These

* Meckel, Archiv für die Physiologie, Bd. I. (1815) t. vi. fig. 1.

are formed by the gradually bent-down ribs*, which are formed in the abdomen either by unusally elongated 'parapophyses' (if they be interpreted by the condition of those elements in the cod-fish), or by pleurapophyses articulated directly to the fibrous sheath of the notochord; which interpretation of the mode of formation of the hæmal arches is supported by Professor Müller's discovery of the nature of those arches in the *Lepidosteus*†. Whether we adopt the analogy of the *Anacanthini*, or the *Ganoidei* (and the general affinity of the *Protopteri* to the ganoids would incline the choice to the latter), the constitution of the hæmal arches in the lepidosiren is strictly piscine; at least if we take the skeleton of the tailed batrachia (fig. 28) as our guide to the homology of the caudal inferior arches in higher reptiles and mammals. The unusual size and length of the abdominal parapophyses in the cod-tribe (*Gadidæ*), the flat-fishes (*Pleuronectidæ*), and the genus *Ophidium*, evinces the natural character of the order *Anacanthini*, in which they have been grouped together by Professor Müller: the pleurapophyses are, conversely, very short and slender in this order. In all bony fishes the costal arch in the abdomen is completed by the aponeurotic septa between the ventral portions of the myocommata‡, which there represent the 'hæmapophyses' (*cartilagines costæ, inscriptiones tendineæ musc. recti abdominis* of anthropotomy). Indeed, when we reflect that the trunk of the fish, by reason of the advanced position of the heart and breathing organs, answers to the abdominal and caudal regions of the trunk of higher vertebrates, we could hardly expect the typical vertebra to be there carried out in osseous tissue; but rather be prepared to find the hæmapophyses retaining the same primitive histological state which they present in the abdomen of mammals and man (fig. 25, *h''*).

Immediately behind the coracoid arch, it is usual to find a long and slender rib-like bone, sometimes composed of two pieces, on each side; it gives a firmer implantation to the portion of the myocommata immediately behind the pectoral fin; and is obviously the ossified serial homologue of the hæmapophysial aponeuroses between the succeeding myocommata. It is usually detached from its centrum and articulated superiorly to the inner side of the coracoid: when it rises higher, as in the *Bqtrachus*, it becomes attached to the atlas, and in the *Argyreiosus vomer* it meets and joins its fellow below, forming a true inverted or hæmal arch, parallel with, but more slender than the coracoid arch. No other idea of the general homology of this arch presents itself than as a hæmal one, completing the costal arch as an ossified hæmapophysis, differing from the typical vertebra (fig. 15) only by the non-development of a sternum or hæmal spine: and there appears to be as little ground for hesitation as to the particular segment of the endoskeleton to which to refer this costal or inverted arch; its immediate succession to the corresponding arch attached to the occiput, as well as the occasional direct attachment, indicating that segment to be the atlas or first vertebra of the trunk.

The best-marked general character of the vertebral column of the trunk in the class *Pisces* is that which Professor J. Müller first pointed out; viz. the formation of the hæmal arches in the tail by the gradual bending down and coalescence of the parapophyses; the exceptions being offered by the ganoid polypterus and lepidosteus and the protopterous lepidosiren. The pleurapophyses are, sometimes, continued in ordinary osseous fishes from the parapophyses after the transmutation of these into the hæmal arches. The dory,

* Linn. Trans. vol. xviii. pl. 23, fig. 4, *x x*.

† Remarks on the Structure of the Ganoidei, in Taylor's Scientific Memoirs, vol. iv. p. 551.

‡ Lectures on Vertebrata, 1846, p. 163, fig. 44, *h p*.

tunny, and salmon yield this striking refutation of the idea of the formation of those arches in all fishes, by displaced, curtailed and approximated ribs. In some fishes, however (*e. g.* the cod), reduced pleurapophyses coalesce with the parapophyses to form the hæmal arches of the caudal vertebræ. The menopome, amongst the lowest or perennibranchiate reptiles, yields a clear disproof of the formation of the hæmal arch in the tail by the pleurapophyses (the parts, viz. called by Geoffroy 'paraux,' and by Dr. Grant 'catavertebral elements' in the abdomen of fishes)*. The vertebral ribs or pleurapophyses in the menopome (fig. 27, *pl*) are short and simple and suspended to the extremities of the diapophyses (*d*) at the beginning of the tail, where they coexist with hæmal arches (*h*, *h*): these must be formed, therefore, by different elements, which, since no trace of parapophyses exists in any part of the spine, I conclude to be the 'hæmapophyses.' The young crocodile and the adult enaliosaurs give the same evidence of the nature of the hæmal arches in the tail, with which the corresponding arches or chevron-bones, in cetacea and many other mammalia, are homologous.

Thus the contracted hæmal arch in the caudal region of the body may be formed by different elements of the typical vertebra: *e. g.* by the parapophyses (fishes generally); by the pleurapophyses (lepidosiren); by both parapophyses and pleurapophyses (*Sudis*, *Lepidosteus*), and by hæmapophyses, shortened and directly articulated with the centrums (reptiles and mammals)†. The caudal vertebræ of some flat-fishes (*Pleuronectidæ*, fig. 16), and the murænæ, would seem to disprove the parapophysial homology of the hæmal arches in such fishes, since transverse processes from the sides of the body coexist with them, as they do in the cetacea. But, if we trace the vertebral modifications throughout the entire column in any of these fishes, we shall find that the hæmal arches are actually parts of the transverse processes; not independent elements, as in the cetacea; but due to a progressive bifurcation: this, in *Muræna Helena*, for example, begins at the end of the transverse processes of about the twenty-fifth vertebra, the forks diverging as the fissure deepens, until, at about the seventy-third, the lower fork descends at a right angle to the upper one (which remains to represent the transverse process), and, meeting its fellow, forms the hæmal arch, and supports the antero-posteriorly expanded hæmal spine. In the plaice a small process is given off from the expanded base of the descending parapophysis of the first caudal vertebra, which increases in length in the second, rises upon the side of the body in the third, becomes distinct from the parapophysis in the fourth, and gradually diminishes to the ninth or tenth caudal vertebra, when it disappears. These spurious transverse processes never support ribs.

The neurapophyses are often directly perforated by the nerves in fishes, but are sometimes notched by them, or the nerves issue at their interspaces.

The neurapophyses, which do not advance beyond the cartilaginous stage in the sturgeon, consist in that fish of two distinct pieces of cartilage; and the anterior pleurapophyses also consist of two or more cartilages, set end on end: and this interesting compound condition is repeated in cases where the pleurapophysial element is ossified and required to perform unusual functions in the bony state in other fishes. Amongst the more special or exceptional modifications of the vertebræ of the trunk of fishes, which indicate the extent to which their normal segmental character may be marked, I would cite those of the anterior vertebræ in the pipe-fishes, in the loaches, and in certain siluroids.

* Outlines of Comparative Anatomy, p. 58, fig. 28, B, *g*.

† By a misconception of the sense in which I use the term 'hæmapophyses,' M. Agassiz has applied it to the laminæ of the inferior or hæmal arches in fishes. "Recherches Poiss. Foss." tom. i. p. 95.

In the *Fistularia tabaccaria* the four anterior vertebræ are much-elongated; the second one even to eight times the length of the ordinary abdominal vertebræ: and their centrums are firmly interlocked together, by very deeply indented sutures. The parapophyses are co-extended with the centrums, and overlap each other, forming a continuous outstanding horizontal ridge on each side; and the neural spines form a similar vertical continuous crest.

In the *Cobitis fossilis* and *C. barbatula* the par- and pleur-apophyses of the second and third vertebræ coalesce and swell out into a large 'bulla ossea' on each side, inclosing the small air-bladder of these fishes: they also lodge the little ossicles which bring this vertebral tympanum into communication with the prolongations or *atria* of the labyrinth *.

In a large South American siluroid fish, I found the fore-part of the vertebral column of the trunk apparently formed by one large vertebra, the body of which sent a broad triangular plate outwards on each side, giving it a rhomboidal figure, viewed from below: these plates in this fish support and coalesce with five parapophyses, which ascend and increase in breadth as they approach the skull, where they join the paroccipitals, as they are, themselves, joined together so as to form a continuous broad oblique outstanding plate of bone. Above these, the continuous bony neural arch is perforated for the exit of five pairs of nerves; the dorsal and ventral roots escaping separately, as in the sacrum of birds. The coalesced neural spines send up a lofty pointed plate to the overhanging supraoccipital. On vertically bisecting this specimen, I found the central parts of the bodies of five vertebræ, which had been developed in the notochord, distinctly marked out, and preserving in their anterior and posterior deep concavities the persistent gelatinous remains of the notochord; although the rest of the circumference of such centrums were anchylosed to the cortical or peripheral parts developed from the capsule of the notochord, viz. to the continuous expanded plate of bone below, to the parapophyses laterally, and to the neurapophyses above. The body of the first vertebra, or atlas, presented the exception of being quite detached from its elevated parapophyses, as well as from its neural arch; it was anchylosed only to the bony plate below. The body of the second vertebra was six times as long as that of the atlas: yet the apices of the two deep terminal jelly-filled cones extended to and met in its centre. The bodies of the third and fourth vertebræ were elongated, but less so than that of the axis: the body of the fifth vertebra was singularly modified; its anterior half presenting the long and slender character of the antecedent vertebræ; whilst the posterior half was suddenly shortened, but extended in depth and breadth so as to adapt its shallow posterior concavity to that of the short and broad body of the first free vertebra of the trunk, which is followed by others of similar character. I have seen few better instances of adherence to type, irrespective of obvious function, than the persistence of the biconcave articular cavities, with the elastic capsules and contained fluid, in the centrums of these five rigidly fixed anterior vertebræ of the siluroid fish.

The continuous bony plate supporting those centrums was perforated lengthwise by the aorta, offering another mode of formation of a hæmal canal, viz. by exogenous ossification in and from the lower part of the outer layer of the capsule of the notochord: the carotid hæmal canal in the necks of birds seems to be similarly formed; and the neck of the ichthyosaurus derives additional strength and fixation from apparently detached developments of bone in the lower part of the capsule of the notochord, at the inferior interspace between the occiput and atlas, and at those of two or three succeeding cervical vertebræ †.

* Weber, G. H., De Aure et Auditu Hominis et Animalium, 4to. 1820.

† Sir Philip de M. Grey Egerton, in Geol. Trans. 2nd ser. vol. v. p. 187, pl. 14.

I am inclined to regard the 'odontoid process' of the mammalian axis as the homologue of one of these subvertebral wedge-bones, or peripheral developments of the outer layer of the notochordal capsule. It cannot be the peculiarly developed anterior articular epiphysis of the second vertebra, since this is represented by a distinct centre of ossification between the odontoid process and the body of that vertebra, according to Professor Müller's observation in a fœtal foal *.

The diverging appendages of the hæmal arch in the abdominal vertebræ of fishes present the form of long and slender spines (fig. 17, *a a*), usually attached to, or near the head of the ribs, and extending upwards, outwards and backwards, between the dorsal and lateral portions of the muscular segments, to which they afford a firmer fulcrum or basis of attachment; acting, therefore, as so many pairs of rudimental and concealed limbs. They are termed the 'obere rippe' by Meckel, and at the fore-part of the abdomen of the polypterus they are stronger than the pleurapophyses themselves. As the vertebræ approach the tail these appendages are often transferred gradually, from the pleurapophysis to the parapophysis, or even to the centrum and neural arch.

In the air-breathing vertebrata, in which the heart and breathing organs are transferred backwards to the trunk, the corresponding osseous segments of the skeleton are in most instances developed to their typical completeness, in order to encompass and protect those organs. The thoracic hæmapophyses in the crocodiles are partially ossified, and in birds (fig. 15, *h*, *h*) completely so; in which class the hæmal spines of the thorax (*hs*) coalesce together, become much expanded laterally, and usually develope a median crest downwards to increase the surface of attachment for the great muscles of flight. This speciality is indicated by the name 'sternum' applied to the confluent elements in question. The abdominal hæmapophyses and spines retain their primitive aponeurotic condition, though still preserving their characteristic expansion †. In the crocodiles and enaliosaurs the abdominal hæmapophyses are also ossified; and, in the latter, they manifest the same composite character which has been noticed in the pleurapophyses of the sturgeon, consisting of three or more pieces, which overlap each other ‡. The abdominal hæmal spines, in the *Plesiosaurus Hawkinsii*, are transversely extended, they are marked *c c* in the figure quoted below: the compound hæmapophyses themselves are marked *b b* in the same figure.

The typical thoracic vertebræ of most birds support diverging appendages (fig. 15, *a*, *a*), either anchylosed or articulated, as in the penguin and apteryx, to the posterior border of the pleurapophysis (*pl*). The function of the appendages in this form of typical vertebra is to connect one hæmal arch with the next in succession, so as to associate the two in action, and to give firmness and strength to the whole thoracic cage. (A portion of the next rib so overlapped is shown at *pl*, *a*, fig. 15.)

With regard to the connections of the pleurapophyses, we have seen that, in fishes, they may be directly attached to the centrum, or to the ends of the parapophyses (fig. 17, *p*), or they may be quite detached from their proper segment, and suspended to the hæmal arch of an antecedent vertebra, as in the case of the clavicle or epicoracoid, no. 28. In batrachians, ophidians, and lacertians, the proximal end of the pleurapophysis is simple, as in fishes, but is articulated to an exogenous tubercle or transverse process from the

* Vergleichende Anatomie der Myxinoiden. Abhand. Akad. der Wissensch. Berlin, 1834, p. 105.

† Myology of Apteryx, Zoological Transactions, vol. iii. pt. iv. pl. 35, *g**, *g**.

‡ Buckland, Bridgewater Treatise, vol. ii. pl. 18, fig. 3.

side of the centrum or the base of the neural arch, called 'diapophysis,' a distinct part from the autogenous parapophyses in fishes. The anterior vertebræ of crocodiles have an exogenous inferior transverse process from the side of the centrum, answering to the 'parapophysis,' as well as an upper transverse process or 'diapophysis' developed from the base of the neurapophysis: and the proximal end of the pleurapophysis bifurcates and articulates with both transverse processes, circumscribing with them a foramen at the side of the centrum. The same structure obtains in the cervical and anterior thoracic vertebræ of birds and mammals: thus the rib (*pl*) in fig. 15 articulates to the parapophysis *p* and the diapophysis *d*. Very few, however, of the thoracic ribs in the cetaceans offer this structure; the first or second may reach the centrum, but the rest are appended to the ends of the long diapophyses, and a character of affinity to the saurians is thus manifested. The cervical region is distinguished by the brevity of the pleurapophyses and the absence of bony hæmapophyses, in saurians, birds, and mammals; but in the warm-blooded classes the short floating vertebral ribs soon anchylose to the diapophyses and parapophyses, and constitute thereby the 'anterior roots of the perforated transverse process' of anthropotomy*. The cervical pleurapophyses are indicated diagrammatically at *pl*, in the neck of the embryo skeleton (fig. 25): those of the seventh cervical vertebræ sometimes attain in the human subject proportions which acquire for them the name of 'ribs.' The pleurapophyses retain their moveable articulation in the ninth, and sometimes the eighth, vertebræ of the elongated neck of the three-toed sloths †.

The thoracic or dorsal vertebræ of mammalia are characterized by the free articulations of the pleurapophyses (fig. 25, *pl*): most of these are much-elongated, and most, if not all, support hæmapophyses (ib. *h*); which, in a greater or less number of the anterior vertebræ, articulate with hæmal spines (ib. *hs*), completing the arch: these spines commonly remain distinct, and are called, some 'sternebers,' others 'manubrium,' and 'xiphoid appendage,' and together they constitute the 'sternum.' In most mammals the thoracic hæmapophyses are cartilaginous: they become ossified in *Dasypus*, *Myrmecophaga*, the megatherioids and monotremes. The hinder pleurapophyses, which progressively diminish in length, also, usually become simply suspended to the diapophyses: all the ribs are so attached in *Balæna longimana*, according to Rudolphi. The lumbar vertebræ, which in some mammals show, in the fœtal state, distinct rudiments of pleurapophyses more minute than those in the neck, have them soon anchylosed to the extremities of the diapophyses, which are thus elongated; and the vertebra is characterized in anthropotomy as 'having no ribs, but simple imperforate transverse processes.' The hæmapophyses of these segments of the skeleton are represented by the 'inscriptiones tendineæ' (fig. 25, *h''*); they do not advance even to the state of cartilage, but retain the primitive condition which they presented in the corresponding part of the trunk in fishes.

If a vertebra succeeding the lumbar or abdominal ones have its hæmal arch completed, as in the thorax, by pleurapophyses and hæmapophyses, with diverging appendages, forming the 'pelvic arch and hind or lower limbs,' it is called a 'sacrum' (fig. 28, D', H, A). If two or more vertebræ anchylose together, without such completion of the typical character, they likewise are said to form a 'sacrum,' of which an example may be found in

* Meckel, Archiv für Physiologie, B. i. (1815) p. 594, pl. vi. fig. 12, *e*; and System der Vergleichend. Anatomie, B. ii. p. 294.

† Prof. Th. Bell, Trans. Zool. Society, i. p. 115. pl. 116, *a*, *b*.

the two or three anterior caudal vertebræ of certain flat-fishes (*Pleuronectidæ**), characterized as usual by the simple parapophysial hæmal arch. In most air-breathing vertebrates the sacrum is characterized by both modifications, which are carried out to their extreme in birds: in no other class is so large a proportion of the vertebral column converted into a 'sacrum' by coalescence (*e. g.* seventeen vertebræ in *Struthio*): in none is the diverging appendage developed to such enormous proportions (*e. g. Apteryx, Dinornis*). The centrums of the middle sacral vertebræ (fig. 27, *c* 1–4) are expanded transversely, but depressed, and converted into horizontal plates: the neurapophyses (*ib. n* 1–4) are lofty, expanded, and arch over the dilated part of the neural canal, lodging the great sacral enlargement of the myelon, with its ventricle. In the young ostrich, before the general anchylosis is completed, the bases of these neurapophyses are found to cross the interspaces of the centrums, and to rest equally upon two of those elements. This modification was retained throughout life, unobliterated by anchylosis, in the sacrum of the extinct dinosaurs (*Iguanodon, Megalosaurus, Hylæosaurus*), and it obtains in the dorsal vertebra of the chelonians. The adjoining portions of the centrums and neurapophysis extend outwards into a short parapophysis, which affords an articular surface of three facets for the short pleurapophysis. One of these elements is figured *in situ* at *pl*, fig. 27; it expands at its distal end, and coalesces there with the contiguous pleurapophyses: the long diapophyses (*d, d*) abut against the inner side, and the ilium applies itself to the outer side of these expanded and anchylosed ends of the short sacral ribs. The spinous processes of the sacral vertebræ (*s, s*) are developed antero-posteriorly, and soon coalesce into a lofty longitudinal crest of bone. In the chelonians, the dorsal spines develope horizontal plates from their extremities, which unite by suture to the similarly united and expanded pleurapophyses, forming with them the 'carapace.' The 'plastron' is formed of the flattened and expanded hæmal spines, which are divided in the middle line, and have an intercalated bone (entosternal) between the halves of the central pieces. Professor Müller has noticed the sacral pleurapophyses in the human and other mammalian embryos†.

As the segments of the endo-skeleton approach the end of the tail, in the air-breathing vertebrates, they are usually progressively simplified; first by the diminution, coalescence and final loss of the pleurapophyses; next by the similar diminution and final removal of the hæmal and neural arches; and sometimes also by the coalescence of the remaining central elements, either into a long osseous style, as in the anourous batrachia, or into a shorter flattened disc "which has the shape of a ploughshare‡," as in many birds. The coalesced representative of the terminal vertebral centrums is developed principally from the outer layer of the fibrous capsule of the primitive notochord. In fishes, however, the seat of the terminal degradation of the vertebral column is first and chiefly in the central elements, which, in the homocercals§, are commonly blended together and shortened by absorption, whilst both neural and hæmal arches remain, with increased vertical extent, and indicate the number of the metamorphosed or obliterated centrums.

* Hunterian Lectures on Vertebrata, 1846, p. 65, fig. 22.

† "Selbst am Kreuzbeine mehrere Thiere giebt es noch abgesonderte Querfortsätze oder Rippenrudimente."—Anatomie der Myxinoiden, heft i. 1834, p. 239.

‡ "La dernière de toutes (des vertèbres de la queue), à laquelle les pennes sont attachées, est plus grande et a la forme d'un soc de charrue, ou d'un disque comprimé:—dans le jeune âge, elle est évidemment composée de plusieurs vertèbres."—Cuvier, Leçons d'Anat. Comp. 2d ed. i. p. 208, and "Lawrence's Blumenbach's Comparative Anatomy," ed. 1827, p. 62.

§ M. Agassiz' expressive name for the fish with a symmetrical bilobed tail.

Summary of modifications of corporal vertebræ.—To sum up the kind and degree of modification to which the several elements of the primary segments of the endoskeleton of the trunk are subject, without masking their general homology, we may commence with the *centrum*; and first, as to its existence. It is wanting, as an ossified part, in the atlas of the wombat and koala*, in which it remains permanently cartilaginous: in the petaurists, kangaroos, and potoroos, ossification extends from the bases of the neurapophyses into this cartilage, but the neural arch or ring long remains interrupted by a median fissure below. In man the rudimental body of the atlas is sometimes ossified from two or even three distinct centres†. The centrums at the opposite extremity of the vertebral column in homocercal fishes are rendered by centripetal shortening and bony confluence fewer in number than the persistent neural and hæmal arches of that part. The centrums do not pass beyond the primitive stage of the notochord in the existing lepidosiren, and retained the like rudimental state in every fish whose remains have been found in strata earlier than the permian æra in Geology, though the number of vertebræ is frequently indicated in Devonian and Silurian ichthyolites by the fossilized neur- and hæm-apophyses and their spines‡. The individuality of the centrums is sometimes lost by their mutual coalescence without shortening.

Although the normal form of the centrum is cylindrical, it may be cubical, conical, hour-glass shaped, like a longitudinal bar, like a transverse bar, like a depressed or a compressed plate, like a ploughshare, &c. The co-adapted terminal surfaces of the centrum may be flat, slightly concave, deeply concave, cupped or conical, concave vertically and convex transversely at one end and the reverse at the other end§; or the fore-end may be concave and the hind-end convex‖; or the reverse¶; or both ends may be convex**; or both ends produced into long pointed processes with intervening deep fissures, so as to interlock together by a deeply dentated sutural surface††.

The centrum may be quite detached from its neural arch (atlas of siluroid and many fishes), and from its hæmal arch (atlas of most fishes).

The centrum may develope not only parapophyses but inferior median exogenous processes, either single, like those of the cervical vertebræ of saurians and ophidians (which in *Deirodon scaber* perforate the œsophagus, are capped by dentine, and serve as teeth‡‡); or double (atlas of *Sudis gigas*§§ and the lower cervical vertebræ of many birds); or the fibrous sheath of the notochord may develope a continuous plate of bone beneath two or more nuclei of centrums, formed by independent ossification in the body of the notochord; these nuclei being partially coherent to the peripheral or cortical plate. The vertebral centrum often shows the principle of vegetative repetition by its partial ossification in the form of two or three bony rings, which answer to a single neural arch (*Heptanchus*‖‖), or by three osseous discs, one for each

* Art. Marsupialia, Cyclopædia of Anatomy and Physiology, vol. iii. p. 277, fig. 99.

† Meckel, Archiv für Physiol. i. taf. vi. fig. 1.

‡ See the admirable Monograph by Agassiz, Sur les Poissons Fossiles du Système Dévonien, 4to, 1846.

§ Most birds.

‖ Existing saurians and ophidians.

¶ Extinct saurian called '*Streptospondylus*;' existing *Salamandra*, *Lepidosteus*.

** 4th cervical of *Emys*, Bojanus, Anat. Test. Europ., tab. xiv. fig. 51, 4. 1st caudal of crocodile.

†† Cervicals or anterior trunk-vertebræ of *Fistularia*.

‡‡ Jourdan, cited in Cuvier's Leçons d'Anat. Comparée, ed. 1835, p. 340, and 'Odontography,' p. 179.

§§ Agassiz in Spix, Pisces Brasilienses, 4to, 1829, p. 6, tab. B, fig. 8.

‖‖ Müller and Agassiz, in Recherches sur les Poissons Fossiles, t. iii. tab. 40ᵇ, fig. 1.

articular surface, and a thicker intermediate piece, as in all fœtal mammals, and throughout life in some cetaceans.

With respect to function, the centrum forms the axis of the vertebral column, and commonly the central bond of union of the peripheral elements of the vertebra: as a general rule it supports, either immediately or through the medium of the approximated or conjoined bases of the neurapophyses, the neural axis (in the trunk called myelon, or spinal marrow, and its membranes); the terminal centrums being usually deprived of this function by the withdrawal of that axis from them in the course of its centripetal or concentrative movement.

The *neurapophyses* are more constant as osseous or cartilaginous elements of the vertebræ than the centrums; but they are absent, under both histological conditions, at the end of the tail in most air-breathing vertebrates, where the segments are reduced to their central elements. The neurapophyses lose their primitive individuality by various kinds and degrees of confluence; as *e. g.* first, of the bases of each pair with their supporting centrum; secondly, of the apices of each pair with one another and with the neural spine,—the lepidosiren affording a rare exception of the persistent individuality of this element and of each neurapophysis throughout the trunk; thirdly, of two or more neural arches with one another, as in the neck of some fishes, cetacea, and armadillos, and in the sacrum of birds and mammals; where they also often coalesce with the pleurapophyses, as they do in the neck of most mammals and birds. The neurapophyses rarely depart from the form of plates, either broad or high, or both; sometimes they are straight, sometimes arched, sometimes bent; sometimes by the inward extension of their bases, they form together a bony ring above the centrum, excluding both that and the spine from the neural canal. The neurapophyses may develope, as exogenous processes, either diapophyses or zygapophyses, and the latter are sometimes double from both the anterior and posterior borders of the plates; as *e. g.* in the vertebræ of *Mugil*, in some serpents, and in the lumbar vertebræ of some mammals. The observed extent of variation of position of the neurapophyses is from the upper surface of their own centrum to above the next intervertebral space, so as to rest equally on two centrums; or they may be uplifted bodily from their centrum, and wedged or suspended between the two contiguous neural arches, as *e. g.* in the atlas of ephippus and other deep-bodied fishes.

Except in the cartilaginous neurapophyses of the sturgeon, I am not aware of any instance of the subdivision of this element into two pieces, placed vertically upon each other. Some plagiostomes show the principle of vegetative repetition in two or three star-like centres of ossification, side by side, in the primitive basis of the neurapophysis, but the second of the two cartilaginous plates on each side of the neural canal, coextensive with the single centrum, in most sharks, which second piece has the form of a wedge with the small end directed down over the intervertebral space, seems to answer, as Prof. Müller has suggested, to the intercalary or interneural piece in bony fishes.

The most constant functional relation of the neurapophysis is to protect the spinal nerve in its exit from the spinal canal, either by a direct perforation of the neurapophysis (many fishes, and some mammals), by a notch in the margin, or by the interspace between two neurapophyses. This function alone is performed, in reference to the nervous system, at the posterior part of the vertebral column in many animals, where the place of the shortened myelon is occupied by the lengthened roots of the nerves: in the rest of the trunk the neurapophyses protect also the neural axis. The original relation of each neurapophysis to the segments of that axis is determined by the place of connection of the perforating nerve with the shortened myelon.

The *neural spine* commonly retains in the trunk the form indicated by its name; but in the atlas of the crocodile, where it is distinct from the neurapophyses, it is a depressed plate. In the thorax and abdomen of chelonians it becomes still more expanded and flattened, and its borders unite by dentated suture to contiguous spines and to the similarly expanded pleurapophyses. The neural spine is absent in the thin annular cervicals of the mole; it is unusually developed and forms a thick square columnar mass of bone in the cervicals of the opossum. It is double in the anterior vertebræ of some fishes: in the barbel one stands before the other; in the tetrodon they stand side by side: and various other minor modifications of this peripheral element might be cited.

The *parapophyses* of the trunk-vertebræ manifest their autogenous character in fishes alone; and in most species the character is soon lost, the parapophyses becoming confluent with the centrum; and, in the tail, either with the pleurapophyses also, or with each other and the hæmal spine, thus completing the hæmal canal (fig. 16). Amongst air-breathing vertebrates the parapophyses of the trunk-segments are present only in those species in which the septum of the heart's ventricles is complete and imperforate, and here they are exogenous and confined to the cervical and anterior thoracic vertebræ, or to the sacrum (as in the ostrich, figs. 15 and 27, *p*). The parapophyses are subject to a certain extent of variation as to form: they are either mere tubercles; or simple, shorter or longer, transverse processes; or they may take the form of long plicated laminæ (in the tails of some pleuronectidæ): they are longer and broader than the pleurapophyses in the cod-tribe; and are sometimes much expanded in the anterior vertebræ of fishes, where they ascend in position, and in the siluroid species above described, coalesce to form a broad outstanding ridge, directed outwards and a little upwards, and rising as they approach the cranium, where they are joined by close suture to the paroccipitals.

The normal function of the parapophyses is to give attachment to muscles and articulation to ribs, and, occasionally, additional strength and fixation to anchylosed portions of the vertebral column. As a rare and exceptional instance, the expanded and excavated parapophyses of the second and third vertebræ in the genus *Cobitis* perform an office closely analogous to one of those of the mastoid in man, since they inclose air-cells brought into communication with the acoustic labyrinth by a chain of small ossicles: and these singularly modified rudiments of the swim-bladder seem to have no other function in the groveling loaches than that in connection with the sense of hearing.

The *pleurapophyses* are less constant elements than the neurapophyses; they exist as free appendages or 'floating vertebral ribs' in the trunk, and sometimes at the fore-part of the tail, in fishes, serpents, and certain batrachians (fig. 28, *pl*). The atlas has its pleurapophyses in most fishes, but they are often detached from their centrum, and sometimes joined to long bony hæmapophyses, as is well-seen in the *Argyreiosus*, and other deep-bodied scomberoids. Ossified hæmapophyses are not present in any other vertebræ of the trunk in fishes. In batrachians the pleurapophyses of the single pelvic vertebra are similarly connected with hæmapophyses, and the costal arch is there completed. In the menopome, the pleurapophysial element of the sacrum, *ib. pl'*, is ossified from two centres. Such typical vertebræ are more common in the higher air-breathing classes. Here the pleurapophyses have generally the long and slender form understood by the word 'rib;' but they expand into broad plates in the thorax of the apteryx, in the anterior thoracic vertebra of whales, and more especially in the carapace of chelonians, where they are joined to each other by suture, and also to the expanded neural spines. These

broad pleurapophyses are occasionally ossified from two centres in the great land-tortoises of India and the Galapagos isles. The free extremities of the short cervical pleurapophyses of crocodiles and plesiosaurs are expanded and produced forwards and backwards, like axe-blades, whence the name of 'hatchet-bones,' applied to them prior to the recognition of their true homology.

The pleurapophyses are appended sometimes simply to the ends of parapophyses; sometimes to the ends of diapophyses; sometimes by a head and tubercle to both kinds of transverse processes; sometimes directly to the side of the centrum; and sometimes they are shifted backwards over the intervertebral space, and are articulated equally to two centrums (human thorax), and sometimes to two centrums, to a neurapophysis and to a long diapophysis, as in the sacrum of the ostrich (fig. 27, *pl*). In the atlas of some fishes the pleurapophysis is detached from its centrum, and is suspended, with its hæmapophysis, from the antecedent hæmal arch (scapulo-coracoid). In some sturgeons the abdominal pleurapophyses are composed of two or more cartilaginous pieces. I have observed some of the expanded pleurapophyses in the great *Testudo elephantopus* ossified from two centres, and the resulting divisions continuing distinct but united by suture. The pelvic pleurapophysis is in two pieces, as a general rule (fig. 28, pl' attached to D'); and the lower piece is the seat of that most common and simple kind of modification, viz. increase of size with change of form from the cylindrical to a flat bone (as indicated by the dotted line in fig. 27), whereby it comes into connection with the pleurapophyses of other vertebræ besides the proximal piece of its own; such pleurapophyses having their development stunted so as not to exceed in size the proximal portion of the pelvic pleurapophysis, whose expanded distal portion (*os*) receives the special name of 'ilium.' This bone retains its rib-like shape however in the chelonians, as in the batrachians: in most species it unites below with two hæmapophyses, called, on account of their modifications of form and proportions, 'ischium' and 'pubis.' The pleurapophyses defend the hæmal or visceral cavity; they are the fulcra of the moving powers which expand and contract such cavity in respiration, when its walls admit of those movements; they frequently support 'diverging appendages,' and give origin to muscles moving such appendages, or acting upon the vertebral column. In some exceptional cases the pleurapophyses become, themselves, locomotive organs, as in serpents and the *Draco volans*.

The *hæmapophyses*, as osseous elements of a vertebra, are less constant than the pleurapophyses; although they sometimes exist in segments, *e. g.* the lumbar vertebræ of certain saurians, and in the case of the ischium, or second pelvic hæmapophysis, in which the corresponding pleurapophyses are absent, or short, or anchylosed to the transverse processes. The only true bony hæmapophyses in the trunk of fishes appear to be those of the atlas, forming the lower piece of the epicoracoid; and of the last (?) abdominal vertebra, forming the ischial or pubic inverted arch supporting the appendages called 'ventral fins.' It is at least to the last abdominal vertebra solely that the homologous arch and appendages are connected, by the medium of the pleurapophyses (iliac bones) in the batrachians, and it needs but the removal of the pleurapophysis, or of its second complementary portion (pl' in fig. 28), to reduce that vertebral segment to the condition which it presents in an abdominal fish. The so liberated inferior (hæmapophysial) portion of the pelvic (last abdominal costal) arch is subject, in fishes, to changes of position far more extensive than have been observed in the neurapophyses or pleurapophyses of the trunk-vertebræ, without however preventing the recognition of the segment to which such shifted hæmapophyses actually and essentially

belong. The homologous hæmal arch exists in the same free and detached condition in cetaceans and enaliosaurs; but in all other air-breathing vertebrates it is connected with the iliac bones and completes the typical character of the proper sacral vertebra. The bony hæmapophyses of the lumbar vertebræ are found suspended in the fleshy abdominal walls of certain saurians: but in the region of the thorax in these and higher vertebrates, the hæmapophysis (fig 15, *h*) articulates by one end to the pleurapophysis (*pl*) and by the other to the hæmal spine (sternal bone, *hs*); or its lower end is attached to a contiguous hæmapophysis; or it is suspended freely from the pleurapophyses (as in the 'floating ribs' of man and mammals), or it may be joined below to the sternum, and have its upper end free, as in the seventh dorsal vertebra of the *Ciconia Argala*. When the upper end of the hæmapophysis articulates with the pleurapophysis in birds, it is usually by a distinct condyloid joint, with smooth articular cartilage and a synovial capsule.

Where hæmapophyses exist in the tail, they articulate directly to the under part of the centrum, or to two centrums at the intervertebral space; and are either free at the opposite end, as in some caudal vertebræ of serpents and in those of the enaliosaurs, or they are confluent with each other at their distal ends; when each pair of hæmapophyses forms the so-called V-shaped or chevron-bone. The changes of position of that detached 'pubic arch' or 'chevron-bone' which supports the ventral fins in fishes afforded Linnæus the characters of the orders 'Abdominales,' 'Thoracici,' and 'Jugulares' in the 'Systema Naturæ'; and its immortal author, in giving the name 'Apodes' to those fishes in which the ventral fins were absent, concisely indicates his perception of their relation to the hind-legs of batrachia and the lower limbs of man. If, then, mere change of relative position, however extensive, failed to conceal the special homology of the detached portion of the pelvic arch and its appendages from the keen-sighted naturalist, still less ought such a character to blind the philosophic anatomist to the general homology of such detached vertebral elements, or prevent his tracing them, wherever he may find them, to the remainder of their proper segment; especially when its place is so clearly and beautifully indicated, as it is by the condition of the pelvic arch in the perennibranchiate reptiles (fig. 28).

The function of the hæmapophyses is to complete, with or without a hæmal spine, the hæmal arch of the vertebral segment; and, in so far to protect the hæmal or visceral cavities and support their contents. They give attachment to the lower or ventral portions of the primary muscular segments 'myocommata'*, called 'intercostals' in the thorax, and 'recti abdominis' in the abdomen of the higher vertebrata; and they thus serve as fulcra to the muscles that expand and contract the abdominal or thoracic-abdominal cavity: and sometimes more directly aid in these movements by the elasticity resulting from an arrest in their histological development at the cartilaginous stage, *e. g.* in the thorax of most mammals. Hæmapophyses may support or aid in supporting diverging appendages; and in giving attachment to the muscles of those appendages. The hæmapophyses are usually slender, longer, or shorter simple bones; but are broad and flat, overlapping each other in the thorax of monotremes: they become broader and shorter in the expanded and fixed thoracic abdominal bony case of chelonians, and are still broader where they close the pelvic arch in the plesiosaurs. In the abdominal region of these extinct saurians and in crocodiles, the freely suspended hæmapophyses are compounded of two or more overlapping bony pieces.

* See the description of these segments, usually confounded under the name of the 'great lateral muscle' or 'longitudinal muscles' in fishes.—Hunterian Lectures on Vertebrata, 8vo, pp. 163–165.

The *hæmal spine* is much less constant as to its existence, and is subject to a much greater range of variety, when present, than is its vertical homotype above, which completes the neural arch. Long, slender, and 'spinous' in the tail, the hæmal spine is reduced to a short and thick bone, often flattened, in the thorax of mammals, a series of thirteen such modified spines forming the so-called 'sternum' in the two-toed sloth: the thoracic hæmal spines are few in number, and are expanded and perforated in the whales: the horizontal extension of this vertebral element is sometimes accompanied by a median division, or in other words, it is ossified from two lateral centres; this is seen in the development of parts of the human sternum: the same vegetative character is constant in the broader thoracic hæmal spines of birds; though, sometimes, as *e. g.* in the struthionidæ, ossification extends from the same lateral centre lengthwise, *i. e.* forwards and backwards, calcifying the connate cartilaginous homologues of halves of four or five hæmal spines, before these finally coalesce with their fellows at the median line. In some other birds, however, there are two or more lateral centres, and usually, also, a median one, from which the ossification of the keel extends downwards, prior to its confluence with the rest of the 'sternum.' In the thorax of chelonians four hæmal spines are established, each by two lateral centres of ossification, forming four pairs of sternal bones with a ninth 'entosternal' piece between the first and second pairs. The 'plastrôn' is the result of this extreme development of the hæmal spines:—the modified moieties of which, remaining permanently distinct and united by suture, have received from Geoffroy St. Hilaire* the convenient special names of 'episternals,' 'hyosternals,' 'hyposternals' and 'xiphisternals,' respectively, as they succeed each other from before backwards.

The *diverging appendages* are, as might be expected, of all the elements of the vertebral segment, the least constant in regard to their existence, and the subjects of the greatest amount and variety of modification. Simple slender spines or styles in fishes (fig. 17, *a a*), simple plates retaining long their cartilaginous condition in crocodiles, short flat slightly curved pieces in birds (fig. 15, *a a*), in some of the lowest species of which, *e. g. Aptenodytes*, they become expanded, like their homologues in the crocodile; such, with one exception, is the range of the variety of form to which these parts are subject in the segments of the trunk. But that exception is a remarkable one: even under its normal ichthyic condition, as a simple style or filament, the diverging appendage of the insulated hæmapophysial portion of the pelvic arch in the protopterus† and lepidosiren‡ is composed of many cartilaginous segments, and projects freely from the surface, carrying with it a smooth covering of integument. In other fishes similar filaments or jointed rays are progressively added to the sustaining arch, which cause a progressive expansion of the common investing fold of skin, forming the organ called the 'ventral fin,' which is accordingly described by the ichthyologist as having two rays (*Blennius*), three rays (*Zoarces*), up to more than twenty rays, (as *Acipenser* in the sturgeons).

When we quit the piscine class we find the diverging appendage of the pel-

* Du Sternum considerée dans les Oiseaux et dans les Poissons. Anatomie Philosophique, p. 69. pl. 2, fig. 21. Here Geoffroy contends that the parts of the hyoid arch (39, 40 and 43) are the homologues of the modified hæmal spines which he calls episternals, hyosternals and hyposternals in the plastron of the turtle: but these names may well be retained, that of 'hyosternal' being used in an arbitrary sense, without reference to the hypothesis which first suggested it.

† Linn. Trans. vol. xviii. pl. 23, fig. 4, *z*. Lectures on Vertebrata, p. 79, figs. 27

‡ Bischoff, *op. cit.* pl. 2, fig. 5, *c*.

vic arch resuming its primitive unity, and with fewer joints than in lepidosiren, but manifesting the principle of vegetative repetition by a bifurcation of the distal segments. Such is its form in the *Proteus anguinus* and in the *Amphiuma didactylum*: in another species of amphiume, the radiated type is more strongly marked by the subdivision of the last segment into three rays, the homology of which with certain of the five terminal rays, called toes or digits in the human foot, is signified by Cuvier's specific name 'tridactylum' applied to this species; the middle segment of the appendage is bifid, the first one is undivided. In the menopome (fig. 28), the proximal segment (63) is likewise single, the second segment (66, 67) double, and a mass of cartilage (68) separates this from the last segment which branches into five jointed rays (69). In the frog two styliform bones are developed in the position of the cartilage (68 in fig. 27), forming a fourth segment of the division: they are replaced by more numerous and shorter bones in higher vertebrates, in which it will be unnecessary to pursue the metamorphoses of the appendage as it is adapted for swimming, steering, balancing and anchoring, for exploration, for burrowing, creeping, walking and running, for leaping, seizing, climbing, or sustaining erect the entire frame of the animal. Its parts under these endless and extreme modifications have necessarily received special names: the first segment (65) is the thigh, *femur*; the second is the leg, and its two rays or bones are called *tibia* (66) and *fibula* (67): the segment (68) is called ankle or *tarsus*, each of its component ossicles having its proper name; and the last radiated segment (69) includes the metatarsus and phalanges: the segments 68 and 69 are termed collectively, the foot, *pes**.

The primitive function of the simple diverging appendages (fig. 17, *a*, *a*) of the abdominal vertebræ in fishes is closely analogous to that of the more developed appendage of the pelvic vertebra, viz. to aid in locomotion, as fulcra to the muscles concerned in that act. In crocodiles and birds they serve to connect one costal arch with the next arch in succession, associating them in action or giving fixity and strength to the whole thoracic cage.

Any given appendage might, however, have been the seat of such developments as convert that of the pelvic arch into a locomotive limb: and the true insight into the general homology of limbs leads us to recognise many potential pairs in the typical endo-skeleton. The possible and conceivable modifications of the vertebrate archetype are far from having been exhausted in the forms that have hitherto been recognised, from the primæval fishes of the palæozoic ocean of this planet up to the present time.

The beneficent Author of all, who has created other revolving orbs, with relations to the central source of heat and light like our own, may have willed that these also should be the seat of sentient beings, suited to all the conditions of animal enjoyment existing in such planets; basking, perhaps, in the solar beams by day, or disporting in the soft reflected light of their earth's satellites by night. The eyes of such creatures, the laws of light being the same, would doubtless be organized on the same dioptric principles as ours; and, if the vertebral column should there, as here, have been adopted as the basis of the higher animal forms, it may be subject to modifications issuing in forms such as this planet has never witnessed, and which can only be conceived by him who has penetrated the mystery of the vertebrate archetype, and recognised the kind and mode and extent of its modifications here.

It is, for example, by no means essential to that organic type that it should be 'tetrapodal': although it best accords with the force of attraction and other

* A remarkable example of the extent to which an early or low form of such segment may be regained by adnormal development in a higher species is given by Kerkringius, Opera Omnia, 4to. 1717, p. 55, tab. viii.

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conditions of our globe, that not more than two pairs of the latent limbs or appendages of the vertebral segments should be developed to serve as locomotive instruments, upon its waters, its atmosphere and its dry land.

The views of the essential relations of such limbs to the vertebrate type which suggest these and similar reflections, may not be accepted by all anatomists: some may be disposed to regard the parts 62 and 64 in fig. 28 as peculiar superadditions, rather than a reappearance of normal elements completing the costal or hæmal arch of a segment of the endo-skeleton and restoring it to its typical condition: and, in the same spirit, they may deny the special homology of the radiated appendage A, with the hinder filamentous fin of the lepidosiren, and the ventral fins of other fishes, and consequently, will repudiate its general homology as the diverging appendage of such hæmal arch, and its serial homology with the simple diverging appendages of the thoracic-abdominal vertebræ of fishes, crocodiles and birds.

I am sensible how large a demand is made on the most philosophic faith in general laws of organization, by seeking acquiescence in the view of the parts of the hind-limb, so variously and definitely modified for special functions, as having for their seat the homologues of segments and rays, which are the result in the first instance of the common course of vegetative repetition of a single vertebral element—an element under all circumstances compounded teleogically, and, therefore, essentially one bone.

But here I must explain what I mean by 'teleological composition.' Individual parts of a skeleton,—what are commonly called 'bones,'—are frequently 'compound' or composed of the coalescence of several primarily distinct osseous pieces. In human anatomy every single and distinct mass of osseous matter entering into the composition of the adult skeleton is called 'a bone'; and Soemmerring, who includes the thirty-two teeth in his enumeration, reckons up from 259 to 264 such bones. He counts the os sphenoccipitale as a single bone, and also regards, with previous anthropotomists, the os temporis, the os sacrum, and the os innominatum, as individual bones; the sternum, he says, may include two or three bones, &c*. But in birds the os occipitale is not only anchylosed to the sphenoid, but they both very soon coalesce with the parietals and frontals; and, in short, the entire cranium proper consists, according to the above definition, of a single bone. Blumenbach, however, applying the human standard, describes it as composed of the proper bones of the cranium consolidated, as it were, into a single piece†. And in the same spirit most modern anthropotomists, influenced by the comparatively late period at which the sphenoid becomes anchylosed to the occipital in man, regard them as two essentially distinct bones. In directing our survey downwards in the mammalian scale, we speedily meet with examples of persistent divisions of bones which are single in man. Thus it is rare to find the basioccipital confluent with the basisphenoid in mammalian quadrupeds; and before we quit that class we meet with adults in some of the marsupial and monotrematous species, for example, in which the supra-occipital, 'pars occipitalis proprie sic dicta,' of Soemmerring, is distinct from the condyloid parts, and these from the basilar or cuneiform process of the os occipitis: in short, the single occipital bone in man is four bones in the opossum or echidna; and just as the human cranial bones lose their individuality in the bird, so do those of the marsupial lose their individuality in the ordinary mammalian and human skull. In many mammals we find th pterygoid processes of anthropotomy permanently distinct bones; even i

* De Corporis Humani Fabricâ, t. i. p. 6.

† Manual of Comparative Anatomy, by Lawrence, ed. 1827, p. 56.

birds, where the progress of ossific confluence is so general and rapid, the pterygoids and tympanics, which are subordinate processes of other bones in man, are always independent bones.

In many mammals, the styloid, the auditory, the petrous, and the mastoid processes remain distinct from the squamous plate of the temporal, throughout life; and some of these claim the more to be regarded as distinct bones, since they obviously belong to different natural groups of bones in the skeleton; as the styloid process, for example, to the series of bones forming the hyoidean arch.

The artificial character of that view of the os sacrum, in which this more or less confluent congeries of modified neural arches is counted as a single component bone of the skeleton, is sufficiently obvious. The os innominatum is represented throughout life in most reptiles by three distinct bones, answering to the iliac, ischial, and pubic portions in anthropotomy. The sternum in most quadrupeds consists of one more bone than the number of pairs of ribs which join it; thus it includes as many as thirteen distinct bones in the *Bradypus didactylus*.

The arbitrary character of the definition of a bone, as 'any single piece of osseous matter entering into the composition of the adult skeleton,' the complex nature of many of such single bones, and the essential individuality of some of the processes of bone in anthropotomy, are taught by anatomy, properly so called, which reveals the true natural groups of bones, and the modifications of these which peculiarly characterise the human subject.

It will occur to those who have studied human osteogeny, that the parts of the single bones of anthropotomy which have been adduced as continuing permanently distinct in lower animals, are originally distinct in the human fœtus: the occipital bone, for example, is ossified from four separate centres; the pterygoid processes have distinct centres of ossification; the styloid, and the mastoid processes, and the tympanic ring, are separate parts in the fœtus. The constituent vertebræ of the sacrum remain longer distinct; and the ilium, ischium, and pubes are still later in anchylosing together, to form the 'nameless bone.'

These and the like correspondences between the points of ossification of the human fœtal skeleton, and the separate bones of the adult skeletons of inferior animals, are pregnant with interest, and rank among the most striking illustrations of unity of plan in the vertebrate organization.

The multiplication of centres from which the ossification of an ultimately single bone often proceeds has especially attracted the attention of the philosophical anatomists of the present century with reference to the right or natural determination of the number of the constituent parts of the vertebrate skeleton. Geoffroy St. Hilaire, in his memoir on the skull of birds, in 1807, says, "Ayant imaginé de compter autant d'os qu'il y a de centres d'ossification distincts, et ayant essayé de suite cette manière de faire, j'ai eu lieu d'apprécier la justesse de cette idée*." Cuvier adopted and retained the same idea to the last. Commenting in the posthumous edition of the 'Leçons d'Anatomie Comparée†' on the character of some of the definitions of single bones in anthropotomy, he, also, concludes that, in order to ascertain the true number of bones in each species, we must descend to the primitive osseous centres as they are manifested in the fœtus. But according to this rule we should count the humerus as three bones and the femur as four

* Annales du Muséum, t. x. p. 344.

† Tom. i. 1835, p. 120. "Mais ces distinctions sont arbitraires, et pour avoir le véritable nombre des os de chaque espèce, il faut remonter jusqu'aux premiers noyaux osseux tels qu'ils se montrent dans le fœtus."

bones, in the human skeleton; for the ossification of the thigh-bone begins at four distinct points, one for the shaft, one for the head, one for the great trochanter, and one for the distal condyles: such deference, however, to the judgment of the great Comparative Anatomist has been withheld by the most devoted of his admirers; whose disinclination to regard these parts and processes as distinct bones is justified by the fact that in birds and reptiles the femur is developed from a single centre.

The rule laid down by the French authorities above-cited fails in its application to the difficult question of the nature and number of bones in a skeleton, because they did not distinguish between those centres of ossification that have homological relations, and those that have only teleological ones; *i. e.* between the separate points of ossification of a human bone which typify vertebral elements, often permanently distinct bones in the lower animals; and the separate points which, without such signification, facilitate the progress of osteogeny and have for their obvious final cause the well-being of the growing animal. The young lamb or foal, for example, can stand on its four legs as soon as it is born; it uplifts its body from the ground and soon begins to run and bound along. The shock to the limbs themselves is broken and diminished at this tender age, by the divisions of the long bones, and by the interposition of the cushions of cartilage between the diaphyses and epiphyses. And the jar that might affect the pulpy and largely developed brain of the immature mammal, is further diffused and intercepted by the epiphysial articular extremities of the bodies of the vertebræ.

We thus readily discern a final purpose in the distinct centres of ossification of the vertebral bodies and the long bones of the limbs of mammals which would not apply to the condition of the crawling reptiles. The diminutive brain in these low and slow cold-blooded animals does not demand such protection against concussion; neither does the mode of locomotion in the quadruped reptiles render such concussion likely: their limbs sprawl outwards and push along the body which commonly sweeps the ground; therefore we find no epiphyses at the ends of a distinct shaft in the long bones of saurians and tortoises. But when the reptile moves by leaps, then the principle of ossifying the long bone by distinct centres again prevails, and the extremities of the humeri and femora long remain epiphyses in the frog.

A final purpose is no doubt, also, subserved in most of the separate centres of ossification which relate homologically to permanently distinct bones in the general vertebrate series; it has long been recognised in relation to facilitating birth in the human fœtus; but some facts will occur to the osteogenist, of which the teleological explanation is by no means obvious.

One sees not, for example, why the process of the scapula which gives attachment to the pectoralis minor, the coraco-brachialis, and the short head of the biceps should not be developed by continuous ossification from the body of the blade-bone, like that which forms the spinous process of the same bone. It is a well-known fact, however, that not only in man, but in all mammals, the coracoid process is ossified from a separate centre. In the monotremes it is not only autogenous, but is as large a bone as in birds and reptiles, in which it continues a distinct bone throughout life. Here, then, we have the homological, without a teleological explanation of the separate centre for the coracoid process in the ossification of the human blade-bone.

This distinction in the nature and relations of such centres is indispensable in the right application of the facts of osteogeny to the determination of the number of essentially distinct bones in any given skeleton.

All those bones which consist of a coalescence of parts answering to distinct elements of the typical vertebra are 'homologically compound.'

All those bones which represent single vertebral elements are 'teleologically compound,' when developed from more than one centre, whether such centres subsequently coalesce, or remain distinct, or even become the subject of individual adaptive modifications, with special joints, muscles, &c. for particular offices.

In the human skeleton, the clavicles, the (thoracic vertebral) ribs, are instances of simple and truly individual bones. The occiput, sphenoid, ethmoid, temporal, superior maxilla, mandible, hyoid, scapula, the so-called true vertebræ, the sacrum and coccyx, the sternum, and ossa innominata are 'homologically' compound bones.

The two parietals are essentially like the frontal and vomer, one 'teleologically' compound bone: so, likewise, are the two nasals. And, if the view of the homology of the jointed filamentary skeleton of the rudimental ventral fin of the lepidosiren with the simple diverging appendages of the costal arches of the abdominal vertebræ be correct, then is not merely the mammalian femur a teleologically compound bone, but the whole skeleton of the hind-limb from the femur to the distal phalanges inclusive must be regarded as representing the essentially single vertebral element, here called 'diverging appendage,' subdivided according to the law of vegetative repetition of centres; which law is progressively overruled and masked by the supervention of the higher law of special modification and adaptation of such vegetative subdivisions to the exigences and habits and sphere of life of the species.

In many animals all the parts of the skeleton of the limbs, and in all animals some of the parts, are simple bones, in the sense of being developed from a single centre; but in none can they claim that essentially individual character which the clavicles and osseous parts of the ribs are entitled to, as being primary vertebral elements.

To trace the mode and kind and extent of modification of the same elementary parts of the typical segment throughout a large natural series of highly organized animals, like the vertebrata; and to be thus led to appreciate how, without complete departure from the fundamental type, the species are adapted to their different offices in creation, brings us, as it were, into the secret counsels that have directed the organizing forces, and is one of the legitimate courses of inquiry by which we may be permitted to gain an insight into the law which has governed the successive introduction of specific forms of living beings into this planet.

Vertebræ of the Skull.—Since it has been found that the bones of the trunk maintain through every kind and degree of adaptive modification, whether as 'thorax,' 'carapace' or 'sacrum,' an arrangement into segments in the constitution and relative position of the parts of which the vertebral type has been universally recognised—let us next examine, without bias, and, if possible, without reference to or recollection of previous attempts, in the first instance, whether such type be traceable through the remaining anterior part of the axis of the endo-skeleton, which, like the thorax and pelvis, has received, on account of its degree of coalescence and other modifications, the special collective term of 'skull;'—or, whether nature has, in this part of the endo-skeleton, so far departed from the pattern on which all the rest is constructed, that we cannot, without manifest violence to her arrangements, demonstrate the segmental composition; or refer, without admitting modifications distinct in kind as well as degree from those that mark the vertebral character in the trunk, the constitution of such segments to the vertebral type.

Taking the conical skull of an ordinary osseous fish—that of the cod (*Morrhua vulgaris*) for example,—if we detach the bones which form its hinder extremity, or base, and which immediately precede and join the atlas, from

those next in advance, we have the circle, or the base bone (1) and arch (2, 3, 4), represented in figure 1, and we also bring away, articulated therewith, an inferior or inverted arch with its appendages, represented in profile outline in fig. 5, 50–57 : the arrow indicating the course of convergence, and its head the point of union, of the two flanks or crura, forming the closing point or crown of such inverted arch.

We have thus removed a segment of the skull, and with as little or even less violence or disturbance to the other bones, than must have been used in detaching a similar segment from the thorax or pelvis of a land-animal. If we compare this cranial segment with the typical vertebra fig. 14, we recognise in the single median bone (1, fig. 1) the *centrum*, by its relative position and its articular surface for the atlas, which retains, moreover, the concave form characteristic of the vertebræ in the piscine class: in the pair of bones (2, 2), which articulate with the upper surface of the centrum, protect the sides of the epencephalon, and are perforated by the 'nervi vagi,' we have the *neurapophyses*: in the single symmetrical bone (3) which completes the arch, and terminates in a crest for the attachment of the uppermost or dorsal portions of the vertebral muscles continued from the trunk, we have the *neural spine*: and in the pair of bones (4, 4), wedged between this spine and the neurapophyses, which give attachment to the inferior arch of the segment (fig. 5, H i), and terminate in a free crest or spine for the attachment of the upper and lateral portions of the vertebral muscles, we have the *parapophyses*; for whose elevated position we have been prepared by their gradual ascent in the anterior vertebræ of the trunk. The rest of this natural segment has undergone the same kind of modification as the thoracic vertebræ present in higher animals (fig. 15), and which consists in the great expansion of the hæmal arch, the removal of the *hæmapophyses* (fig. 5, 52) from the centrum (*ib.* 1), and the interposition of elongated and deflected *pleurapophyses* (50, 51): finally, the great inverted arch, so formed, encompasses, supports and protects the heart, or centre of the hæmal axis. The elements of this arch are open to two interpretations according to the type of figure 15: either 50 may be *pl*, 51, *h* and 52 *h s*; or 50 and 51 may be a divided (teleologically compound) pleurapophysis, and 52 an unusually developed hæmapophysis: and this latter conclusion is more agreeable with the character of the vertebral segments of the trunk in fishes, in which the hæmal spines are absent, the hæmapophyses, when ossified, long and sometimes joined together at their lower ends, as *e. g.* in the first trunk-vertebra of *Argyreiosus vomer*, and the pleurapophyses sometimes, as *e. g.* in the sturgeon, composed of two or more pieces, set end to end. The condition of the pleurapophysis of the pelvic arch in the menopome (fig. 28, 62, *pl*), which sustains a radiated appendage (*ib.* A) of the hæmal arch of the occipital vertebra, indicates the true character of the pleurapophysis: and the modifications of this arch in the higher classes will be found to establish the accuracy of the general homology of the bone 52, with the hæmapophysial element, since the lower extremities of 52 are actually drawn apart and articulated to a hæmal spine, which completes the arch below in reptiles and birds (fig. 22, H *s*).

Even should there be error in assuming the subdivision of the pleurapophyses and the absence of the hæmal spine, in the particular determination of the constituent elements of the arch in question, yet the alternative is still within the recognised limits of the vertebral modifications of the trunk; and the want of unquestionable proof of the precise elements forms no valid objection to its general homology as a hæmal vertebral arch, expanded and modified after one or other of the types of those which, in the thorax of the air-breathing vertebrates, encompass and protect the more backwardly r

centres of the vascular system (heart and lungs); according to which types, for example, it may be either closed below by the meeting of the sternal ribs (hæmapophyses) or by the intervention of a single or divided sternal bone (hæmal spine). And, further, since in fishes, as the lowest class of vertebrata, the vegetative character of repetition of forms, proportions and composition in the successive segments of the skeleton prevails in a greater degree than in any of the higher classes, so we may conclude that this hæmal arch presents, by its articulation with the epencephalic neural arch, its normal position; and that the whole occipital vertebra here manifests its veritable and typical character.

As the hæmal arches in the trunk of fishes commonly support diverging appendages, which project freely outwards and backwards, but are hidden and buried in the muscular masses to which they give attachment, so the occipital arch, also, commonly supports its diverging appendages. They are absent in *Gymnothorax* and some other *Muræniдæ*. The appendage is present in the form of a single multiarticulate filament in the eel-like protopterus* and lepidosiren†; it is modified by that mode of vegetative repetition which results in adding to the number of similar filaments directly articulated to the supporting arch; and is further complicated by the expansion or confluence of the proximal joints in different degrees as they recede from the supporting arch, so as to constitute definable segments of the appendage‡.

Such is the condition of the part in most osseous fishes, and such is shown in the diagram of the base of the appendage in figure 5; where the proximal segment consists of two broad and flat bones (54 and 55), the next segment of five narrower and shorter but thicker bones (56), and the last segment of more numerous bones of the primitive filamentary form and multiarticulate structure, which bifurcate and radiate as they recede from the centre of attachment.

We may connect the tendency to extreme and variable development in the peripheral parts of a vertebral segment, with the freedom which is the necessary consequence of their position: they are attached by one end only, they have not, therefore, that physical restraint to growth which may arise out of the fettering by both extremities, which characterizes the more central vertebral elements entering into the composition of the neural and hæmal arches. Even in these we find the disposition to luxuriant growth or vegetative subdivision greatest in the peripheral elements, viz. the neural and hæmal spines: much more, therefore, might it be expected in the less constant, diverging, and commonly freely projecting appendages of the vertebral arches. Although here the polarizing forces which tend to shoot out particle upon particle after the pattern of dendritic corals, plants or crystals, are so controlled by the antagonizing principle of adaptation, that the radiating growth is always checked at that stage and guided to that form which is suited to the wants and required by the mode of life of the species.

Since, however, we are able to retain firmly and with certitude our recognition of the special homology of the diverging appendage of the occipital hæmal arch, through all its modifications, from the single ray of the lepidosiren to the hundred-fold repetition of the same elements with superadded dichotomous bifurcations sustaining the enormous pectoral fins of the broad and flat plagiostomous fishes thence called 'rays' *par excellence*, so we can retrace, with equal certitude, the serial homology of this appendage, when it is so plainly manifested by its simple form as well as connections in

* Linnæan Transactions, vol. xviii. pl. 23, fig. 4, *w*.
† Bischoff, *Lepidosiren paradoxa*, 4to, pl. 2, fig. 4, *c*.
‡ Hunterian Lectures on Vertebrata, figs. 27, 40, 41, 42, 43, 7*a*.

the lepidosiren, the amphiuma or the apteryx, with the scarcely more simple or less-developed appendage of the thoracic abdominal hæmal arches (ribs) of birds and fishes (figs. 15 and 17, *a*, *a*); and thus we are led to determine its general homology, under its manifold forms of fin, fore-limb, wing, or arm, as the diverging appendage of the hæmal arch of the occipital vertebra.

The natural and typical vertebral segment above-defined cannot be detached, in every fish, by the mere disjunction of sutures: in the lepidosiren, *e. g.* the ossified part of the centrum has coalesced with that of the next segment in advance and would require to be divided by the saw: the same coalescence occurs in the human skull, and has led to the definition of the cranial bone, called 'os spheno-occipitale*.' In osseous fishes, either by connation of *s* with *s*, fig. 5, or by excessive development of bone in the notochordal capsule extending forwards from the centrum *s*, and producing *s*, there results the long bone (*s*, *s*) continuing the series of vertebral centrums forwards, and corresponding in position with two segments or arches above. On the hypothesis that it represents the central elements of both those arches, it must be divided artificially, in order to separate that segment of the cranium which next succeeds the occipital one. And, further, either by a similar coalescence of the proximal elements of two hæmal arches, or by the undue extension of such element of one of the arches, interposing itself between the next arch and the rest of the vertebra to which that arch belongs, it happens, that unless the proximal element or elements in question be artificially divided, as at *2sa*, *2sa*, fig. 5, two hæmal arches (H II and H III) would be brought away, with the neural arch detached by the separation of sutures and the division of the bone *s*, *s*. If neither that bone, nor *2sa* were divided, but were, with the bones in superior connection with them, separated from the bones anteriorly articulated to them by suture, then we should have the group of bones, included by the curved lines marked N II, N III, H II, H III in fig. 5. Two vertebral segments are plainly indicated in this group by the distinct hæmal arches and their appendages, H II and H III; but three pairs of bones, *ic*, *c* and *ic*, fig. 5, appear to be in neurapophysial relation with the single and symmetrical median bone *s*, *s*. If, however, what has been urged in the chapter on 'Special Homology' (pp. 188–196) respecting the petrosal character of *ic* be a true interpretation of that bone, then we must eliminate it from our present inquiry, inasmuch as being a partial ossification of a sense-capsule (and nature herself removes them, as such, in most fishes), it appertains to a category of bones (splanchno-skeleton), forming no part of the proper neuro- or endo-skeleton, in which alone we seek for evidence of a segmental disposition of parts corresponding with the segments of the nervous system.

The bony petrosals (*ic*) being removed, let us, then, with the view of examining the composition of the segment of the skull with which the occipital vertebra was articulated, saw across the bones *s*, *s* and *2sa*, and separate the bones *e*, *7*, *s* from their sutural connections with those in front of them. In thus obtaining the segment in question, the opponents to the vertebral theory of the skull are entitled to assert that violence is done to nature by the sections of the single bones above-cited; the validity of which as an objection to that theory will be afterwards inquired into.

It is not, however, absolutely necessary to divide the basal bone *s*, *s*: in many osseous fishes a symmetrical bone (fig. 5, *s'*) supports the parial bones *ic*, and stands in the relation of a centrum to them; the neural arch or circle of that segment would not, therefore, be broken by the removal with the posterior segment of the whole of the bone *s*, *s*. If the corresponding

* See Table I., Soemmerring.

development from the under part of the centrum of the second cervical vertebra of the siluroid fish (p. 260) were removed, with that segment, from the atlas, the atlantal neural arch would still be completed by the rudimental body, beneath which the ossification from the succeeding vertebræ had extended itself.

Whether, however, we divide or not the bone 8, 9, those which rest upon its posterior or basisphenoidal part present, after the removal of the petrosals, when viewed from behind, and slightly disarticulated from each other, the arrangement exhibited in fig. 2. The bones 6, 6 support and defend the lobe of the third ventricle or the mesencephalic segment of the brain; they give exit to the trigeminal nerves (*tr*), and thus, as well as by their connections with the other bones of the arch, repeat the *neurapophysial* characters of the bones 2, 2 in the occipital segment. The bones 8, 8, by their more external position, by affording an articular surface to the hæmal arch (*sa*, H 11), and their development of a strong transversely and backwardly produced process for muscular attachments, obviously repeat the *parapophysial* characters of the bones 4, 4 in the occipital vertebra.

The arch is not completed above in the cod-fish; the bones 7, 7 being separated at the mesial line by the interposition of the produced spine of the occipital vertebra 3, which joins with 11. In some other fishes, however, *e. g.* carp and pike, the bones 7, 7 do come in contact and join each other by a 'sagittal' suture, thus completing the neural arch. It will afterwards be seen, by tracing the homologues of these bones in other animals and their homotypes in other segments, what value may be assigned to the objection to their general homology as the crown or hæmal spine of the mesencephalic neural arch, founded upon the median division and occasional divarication of the two halves of no. 7 in osseous fishes. I may so far anticipate the discussion as to remark that, even in the present group of vertebrates, the spine of the occipital vertebra (3) is divided by a median suture in the lepidosteus; so that the condition of the epencephalic arch in that fish is precisely that of the mesencephalic arch in the carp, and essentially the same as that in fig. 2, and in most other osseous fishes.

The remainder of the second or parietal segment of the skull, H 11, repeats the expanded modification of the hæmal arch of the occipital vertebra, and even approaches nearer to the character of the thoracic vertebræ of the higher animals, by the development of single symmetrical bones at the crown of the inverted arch. But the principle of vegetative repetition is still more manifested in this arch than in the occipital one. If we regard the posterior half of the epitympanic, *sa*, as the proximal piece of the parieto-hæmal arch, which has coalesced with the corresponding piece of the fronto-hæmal arch, then the *pleurapophysis* of the parieto-hæmal arch will consist, in bony fishes, of two pieces, *sa* and *ss*, like the pleurapophysis of the occipito-hæmal arch, *so* and *si*. The bones, *ap* and *ap*, represent the *hæmapophysis* of the parieto-hæmal arch. The two pairs of small bones (41) with the single median anterior (*a*) and posterior (43) appendages, represent a still more subdivided spine or keybone of this inverted arch.

Beneath this mask of multiplication of bony centres, the broad characters of the inverted arch suspended to the parapophyses of the parietal vertebra, as the hæmal complement of that natural segment of the skull, stand boldly out: it encompasses, sustains and protects the branchial organs—the analogues of lungs—the next great development of the vascular system anterior to the heart; and the subdivision of the piers of this expanded arch relates to the necessity for a combination of strength, with flexibility and elasticity, in the execution of the movements producing the respiratory currents.

The correspondence with the scapular, or occipito-hæmal arch, is further carried out by the presence of *appendages* (44) which freely diverge from it, but the development of these appendages has not been observed to extend beyond that second phase, marked by vegetative multiplication of the simple ray, directly attached to the arch itself. The lepidosiren offers the simplest condition of such 'diverging appendage' in the single slender bony piece connected with the element 40*. Cuvier and other ichthyologists cite a series of stages of this kind of development of the hyoidean appendage from a similar simple beginning up to a 30-fold repetition of the single ray (*Elops*); and the 'branchiostegal' rays have been found in much greater numbers in certain fossil fishes. Like the 'pectoral' rays, they support a duplicature of membrane, which plays freely backwards and forwards, reacting upon the ambient medium, and forming, in short, a cephalic fin, but with its powers so restricted and adjusted, as to propel the water through the branchial chambers of the fish, instead of driving the fish through the water; in which latter action, indeed, the occipital appendages (pectoral fins)in most osseous fishes can and do perform but a very small share.

If we next proceed to compare the frontal segment, N III and H III, dismembered as above described from the parietal vertebra, and, by the separation of the sutures, from the bones terminating the skull anteriorly, we shall find a neural arch (fig. 3) closely repeating the characters of that of the occipital vertebra. The *centrum* is sometimes represented simply by the forward extension of ossification of the basisphenoid (11), which I regard as the homotype of the ossification of the capsule of the notochord beneath the centrums of the anterior trunk-vertebræ in the silurus; sometimes, also, of a distinct superincumbent symmetrical ossicle (9′, fig. 5), answering to the rudimental (central part of the) body of the atlas supported by the inferior bony plate, in the silurus. This more complex condition of the centrum of the frontal vertebra is well-seen in the sword-fish. The bones 10, 10, which directly rest upon 9′, when it exists, which defend the sides of the prosencephalon, and which are either grooved by the optic nerves, or have those nerves perforating the fibro-cartilaginous membrane close to the margin of the bone (10) from which it is continued, are obviously the *neurapophyses*. They are, however, small; inasmuch as the segment of the brain to which they relate is of inferior size in bony fishes: and they are still smaller in comparison with the spine (11) which is enormously expanded, in relation to its accessory functions as the chief contributor to and protector of the orbits. The bones 12, wedged between the neurapophyses and spine, affording an articular surface to the proximal piece of the hæmal arch, and developing a transverse process for muscular attachments, are the *parapophyses*. The bones (17) have as little essential connection with the typical neural arch above demonstrated, as the bones 16, 16″ had with the corresponding arch of the parietal vertebra: and their more peculiar form in relation to the ball which they protect, and their variable histological condition in the vertebrate series, have not only prevented their ever being mistaken for parts of cranial vertebræ, but have led to the opposite extreme of excluding them altogether from the bones of the skull, with which they are as much entitled to rank as the petrosal (16) or the turbinal (19); but always in the category of sense-capsules or 'splanchno-skeletal' pieces.

In regard to the inferior arch of the frontal segment, the subdivision of its constituent elements, in subserviency to its special functions, is carried to as great an extent as in that of the parietal segment. I regard the four overlapping and closely-connected pieces from the upper joint (28*a*) to the lower

* Hunterian Lectures on Vertebrata, p. 79, fig. 27, 27.

joint (*22d*) inclusive, as the *pleurapophysis*: it is not so obvious whether the bones 29–32 form a subdivided *hæmapophysis*; or whether the terminal bone (32), forming by symphysis with its fellow the crown of the inverted arch, may not be the moiety of a mesially divided *hæmal spine*. But the general character of the inverted arch (H III), as the hæmal complement of the frontal vertebra is unmistakeable, and its serial homology with the succeeding arches (H II and H I) is fully illustrated in fishes by its supporting *diverging appendages* (24–27). These, in the series of fishes, manifest, in as many permanent arrests, the chief phases of development that the corresponding appendages of the occipito-hæmal arch have been described to pass through. The diverging appendage of the fronto-hæmal arch is a single and simple bony style in the lepidosiren; it consists of three or four simple rays in the monk-fish and some other plagiostomes; it has one ray expanded into a broad proximal piece in the conger, which sustains a distal segment of the appendage, one member of which, the 'subopercular,' still retains the long and slender, ray-like form, which is, also, clearly traceable in the broader but long and curved 'opercular'; in the cod, as in most osseous fishes, the parts of the second segment of the appendage (25, 26, 27, fig. 5) are metamorphosed, like the proximal one (24), into broad and flat bones. The fin-like fold of integument, sustained and moved by means of this diverging appendage and its muscles, reacts upon the surrounding water; but, like the hyoid-fins, with which the tympanic or opercular fins are closely connected, they are chiefly subservient to the creation of the respiratory currents and their direction through the gill-chambers. The weight of these appendages, and the constant movements in connection with respiration, as well as those which the hæmapophysial portions of the arch, modified in subserviency to nutrition have to perform, as jaws, explain the necessity of the subdivision of the supporting pedicle into overlapping pieces allowing of a certain elastic yielding with recoil, and thus diminishing the liability to fracture without affecting, except by increasing, the strength of the arch. The trochlear joint between the two elements of this arch (at *22d* and 29) with its cartilage and synovial sac, repeats the complex structure of the articulation between the vertebral and sternal portions of the ribs in birds. To the fore-part of the lower piece (*22d*) of the pleurapophysis is usually articulated a bone (24) connecting it with another bone (20) in advance: the ground for regarding 24 as appertaining to the arch (20, 21 and 22, H IV) will be explained in the description of that arch.

There remains, then, in the fish's skull, to be considered, the group of bones (N IV, H IV, fig. 5) forming its anterior extremity; and we have to inquire, whether there can be traced in this easily separable group such a concordance in its formation with the arrangement of the constituents of the foregoing segments as will justify its being regarded as a natural segment of the skull, and as still illustrating the type on which all the other segments of the endoskeleton have been constructed. Fig. 4 gives the same view of the bones of this group in vertebral relation with the rhinencephala as the views in figs. 1, 2 and 3 do of the bones having a similar relation to the three larger segments of the brain: we perceive the single and symmetrical bone (12) forming the basis of the arch, and sustaining the bones 14, 14, which more immediately support the olfactory ganglions and transmit their nerves, either by grooves or foramina, to the olfactory capsules: the key of the arch is formed by the single and symmetrical bone 15, which is articulated to and chiefly sustained by the bones 14, 14: but 15 is expanded and deflected anteriorly so as to rest directly upon 13 and completely obliterate the neural canal; the hæmal canal being in like manner closed by the approximation of

the hæmal spine (22) to the nasal centrum (13), and by the upward development of the processes of 22 which join the neural spine (15). Much modification was to be expected in the segment which terminates the skeleton anteriorly; and yet the typical characters of the neural arch are more completely preserved here than at the opposite end of the vertebral column. If the bones 4, 8, 12, which I recognise as 'parapophyses' in the cranial segments I, II, III, must be viewed as superadded intercalations for the special and characteristic expansion of the neural arches of those segments—normal elements, indeed, of the typical vertebra, but with modified connections for cranial functions—then the disappearance of their homotypes in the nasal segment restores its neural arch (fig. 4) to the more common condition, and we recognise in 13 the *centrum*, in 14, 14, the *neurapophyses*, and in 15 the *neural spine* of the nasal vertebra.

But the segment to be complete should exhibit a second arch, inverted; and we find such arch closed or completed by the symphysis of the bones 22, fig. 5, and suspended to the sides of the centrum 13 and to the neurapophyses 14, 14, by the bones 20, as the piers or crura of the arch; these bones being connected to the key-bones 22, by the intermediate bones 21. Now, the modifications which these elements of the inverted or hæmal arch of the nasal vertebra have undergone, are, also, much less than might have been anticipated from the extent to which the segments are modified at the opposite extreme of the endoskeleton. All the normal elements of the hæmal arch, for example, are retained: 20 is the *pleurapophysis*, 21 the *hæmapophysis*, and 22 the *hæmal spine*, in most fishes divided at the middle line, but sometimes confluent with its fellow *e. g. Diodon*. The essential (pleurapophysial) part of 20 extends in many fishes (*e. g.* percoids) like a short straight rib from its articulation with 13 and 14 to the condyle at its opposite end to which the hæmapophysis 20 is articulated; but it usually, also, developes a process from its hinder margin downwards and backwards, which gives attachment to the diverging appendage of the arch H IV. The development of the other bones of the arch, 21 and 22, outwards, downwards and backwards, is still more marked in relation to the protractile and retractile movements of the arch in most osseous fishes; and some anatomists, influenced by the form and proportions rather than the connections of those bones, have described them as independent parallel arches: but, as such, they must be regarded as being suspended by their apices or key-stones to the axis of the skull, and as having their haunches hanging freely downwards and outwards—a position the reverse of that of the foregoing inferior arches of the skull and of every typical hæmal arch. The reduction of that divergent development, characteristic of the bones 21 and 22 in fishes, is effected in a great degree within the limits of the piscine class: already we find one of the spurious arches abrogated in the salmonoid fishes by the shortening of 22, and its more direct continuation from 21, which now forms the larger part of the upper border of the mouth and supports teeth: the confluent maxillaries and premaxillaries send down only a single divergent process from their point of suspension to the palatine condyle in the plectognathic fishes; and the consolidation of all the elements of the palato-maxillary arch into its normal unity is effected in the lepidosiren*. The palatines (20) always form the true bases or suspensory piers of the inverted hæmal arch at their points of attachment to the prefrontals (14); the premaxillaries, 22, constitute the true apex or crown at their symphysis or point of confluence, H IV; the approximation of which to the anterior end of the axis of the skull is rendered possible, in fishes, by the absence of any air-passage or nasal

* Hunterian Lectures, Vertebrata, p. 81, fig. 29.

canal. The diverging appendage, sometimes single and anchylosed to the arch (lepidosiren); sometimes single and detached like a long, narrow bone (some murænoids); more commonly consists of two bones (23, 24), which extend outwards, downwards, and backwards from the pleurapophysis (20); but the more constant and better ossified bone of the two, no. 24, articulates posteriorly with the succeeding pleurapophysis (28) and combines its movements with those of its own arch, just as the diverging appendages of one thoracic hæmal arch in the bird associate the movements of that arch with those of the next in succession (as in fig. 15, *pl*, *a*, *pl*). The hæmapophyses here, as at the opposite end of the body, begin so far to dissociate themselves from the pleurapophyses as to articulate also directly with the centrum (13) as well as with the pleurapophyses. I regard this as a very interesting approximation to that condition of the typical vertebra which is illustrated by the diagram (fig. 14), and which is seen in nature in the caudal vertebræ of the crocodiles, enaliosaurs and menopome (fig. 28, H).

From the foregoing analysis it appears, then, that in osseous fishes the endoskeletal bones of the head are arranged, like those of the trunk, in segments; that these are four in number, and that they closely conform to the character of the typical vertebra.

Thus we have four centrums and neural arches: viz.

N I. Epencephalic arch (figs. 1 and 5, 1, 2, 3, 4);
N II. Mesencephalic arch (figs. 2 and 5, 5, 6, 7, 8);
N III. Prosencephalic arch (figs. 3 and 5, 9, 10, 11, 12);
N IV. Rhinencephalic arch (figs. 4 and 5, 13, 14, 15).

As a collective name for the sum of these immoveably articulated arches would be as convenient as the anatomist finds the names 'sacrum' and 'carapace,' applied to similarly consolidated portions of vertebral segments in the pelvic and abdominal regions of certain air-breathing vertebrates, that of 'cranium' may well be retained for the neural arches of the skull: but it should be understood to signify, in all animals, the bones 1 to 15 inclusive; whereas it has, hitherto, been applied variably in different species; sometimes including sense-capsules and facial bones, intercalated to expand the walls of the cavity for a large brain; and more frequently excluding true cranial bones, those of the rhinencephalic arch, for example, which encompass as essential a part of the encephalic chamber, as the sacral vertebræ do of the neural canal at the opposite end of the vertebral axis; although in both instances the extremities of the neural axis may have been withdrawn, in the course of its concentrative change and movement, from their original seat.

The hæmal arches indicated by the arrows in fig. 5, the heads marking the point of junction or crown, are,—

H I. Scapular arch (50–52);
H II. Hyoidean arch (38–42);
H III. Mandibular arch (28–37);
H IV. Maxillary arch (20–22).

The diverging appendages of the hæmal arches are,—

1. The Pectoral (54–57);
2. The Branchiostegal (44);
3. The Opercular (34–37);
4. The Pterygoid (23–24).

The bones or parts of the splanchno-skeleton which are intercalated with or attached to the arches of the true vertebral segments, are,—

The Petrosal (16) or ear-capsule, with the otolites, 16″;
The Sclerotal (17) or eye-capsule;
The Turbinal (19) or nose-capsule;
The Branchial arches;

The Teeth.

The bones of the dermo-skeleton are,—

The Supratemporals;

The Supraorbitals;

The Suborbitals;

The Labials.

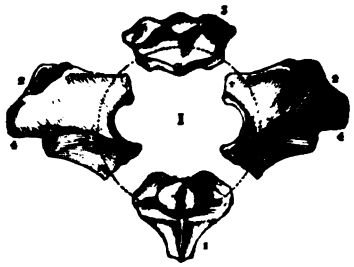
Such appears to be the natural classification of the parts which constitute the complex skull of osseous fishes.

As the object of the present report relates chiefly to the endoskeleton, I have only added the osseous parts of the sense-capsules to the cranial vertebræ in fig. 5; omitting the branchial arches and dermal bones: the hæmal arches and their appendages are given in diagrammatic outline.

Reptiles.—In proceeding with the inquiry into the natural arrangement of the skull-bones, I have selected from the *Reptilia* the crocodile, as a typical example of that class, and one most likely to facilitate the inquiry on account of the characteristic persistence of the primitive cranial sutures.

Pursuing the same mode of investigation as in the case of the fish, let us disarticulate the hindmost segment of the skull and so detach the four bones, represented in fig. 18. The dotted circle indicates the points at which these bones are joined together, in order to encompass the epencephalon, or hindmost segment of the brain. No. 1 is the *centrum*; 2, 2 are the *neurapophyses* with the coalesced *parapophyses* (4, 4); and 3 is the *neural spine*. This element differs but little in size and shape from the similarly detached and depressed neural spine of the atlas of the crocodile. The single convex condyle at the back part of no. 1 makes that centrum resemble the posteriorly convex bodies of the trunk-vertebræ in as striking a manner as the repetition of the articular concavity in the basioccipital of the cod (fig. 1, 1) marks its serial homology with the succeeding vertebral centrums of the same animal. In the descending process from the under part of the occipital centrum of the crocodile (fig. 18, 1), we see a second character of the cervical centrums in that reptile repeated, viz. their inferior exogenous spine. The neurapophyses (2, 2), like those of the atlas, meet above the neural canal: they give exit to the vagal and hypoglossal nerves, and protect the sides of the medulla oblongata and cerebellum. The neural spine (3) protects the upper surface of the cerebellum: it is also traversed by tympanic cells, and assists, with the bones 2, 2, in the formation of the chamber for the internal ear. The special homology of the outstanding processes (4, 4) in the crocodile and serpent (fig. 10), with the similarly situated but distinct 'paroccipital' bones in the cod, is confirmed by their resuming their independency in the hinder segment of the skull of the chelonian reptiles; and the occipital neural arch of the crocodile is reduced by their confluence with the neurapophyses to the condition of those of the trunk-vertebræ, as composed, viz. of instead of six elements.

Fig. 18.



Disarticulated epencephalic arch, viewed from behind: Crocodile.

The epencephalic arch offers the same simple condition not only in ophidians but in most saurians: the chameleons however retain,

chelonians, the ichthyic independence of the parapophyses (4, 4). In batrachians the epencephalic arch is reduced to the two important elements, the neurapophyses; which meet and join each other below as well as above the foramen magnum, and develope the exogenous zygapophyses, or two occipital condyles, for articulation with the corresponding processes of the neural arch of the atlas. The basioccipital, if it exists in batrachians, is rudimental and confluent with the basisphenoid, and the supraoccipital is in like manner recognisable only as the posterior border of the backwardly produced parietal. The parapophyses are short exogenous processes of the neurapophyses of this much simplified epencephalic arch in all batrachian reptiles.

The chief modification that distinguishes the above-described segment of the crocodile's skull from its homologue in the fish, is the absence of an attached inverted or hæmal arch. We recognise, indeed, the special homologues of the piscine constituents of that arch in *so*, *s1* and *s2*, fig. 22. The upper suprascapular piece (*so*) is however free, disconnected from any segment, and retains, in connection with the loss of its proximal or cranial articulations, its cartilaginous state: the scapula (*s1*) is ossified, as is likewise the coracoid (*s2*), the lower end of which is separated from its fellow by the interposition of a median, symmetrical, partially ossified piece called 'episternum' (*hs*). The power of recognising the special homologies of *so*, *s1*, and *s2* in the crocodile, with the similarly numbered constituents of the arch H 1 in fishes (fig. 5), though masked not only by modifications of form and proportion but even of very substance, as in the case of *so*, depends upon the circumstance of these bones constituting the same essential element of the archetypal skeleton: for although in the present instance there is superadded to the adaptive modifications above cited the rarer one of altered connections, Cuvier does not hesitate to give the same names (suprascapulaire) to *so* and (scapulaire) to *s1*, in both fish and crocodile: but he did not perceive or admit that the narrower relations of special homology were a result of, and necessarily included in, the wider law of general homology. According to the view of this law here taken, we discern in *so* and *s1*, fig. 22, a teleologically compound *pleurapophysis*, in *s2* a *hæmapophysis*, and in *hs* the *hæmal spine*, completing the hæmal arch.

The general relations of the scapulo-coracoid arch to a hæmal or costal one have been long recognised, but the vertebral segment to which it appertains seems not hitherto to have been suspected, and has certainly not been satisfactorily determined. Oken, who had observed the free cervical ribs in a specimen of the *Lacerta apoda*, Pallas (*Pseudopus*), deemed them representatives of the scapula, and this bone to be, in other animals, the coalesced homologues of the cervical pleurapophyses*. In no animal are the conditions for testing this question so favourable and obvious as in the crocodile: not only do cervical ribs coexist with the scapulo-coracoid arch, but they are of unusual length and are developed from the atlas as well as from each succeeding cervical vertebra: we can also trace them beyond the thorax to the sacrum, and throughout a great part of the caudal region, as the sutures of the apparently long transverse processes of the coccygeal vertebræ demonstrate in the young animal; the lumbar pleurapophyses being manifested at the same period as cartilaginous appendages to the ends of the long diapophyses.

* "Auch die Scapula nicht *ein* Knochen, sondern wenigstens eine aus fünf Halsrippen zusammengeflossene Platte ist."—Programm, &c., 4to, 1807, p. 16. He reproduces the same idea of the general homology of the scapula in the 'Lehrbuch der Natur-philosophie,' 1843, p. 331, ¶ 2381. Carus also regards the scapulo-coracoid arch as the reunion of several (at least three) protovertebral arches of the trunk-segments. 'Urtheilen des Knochen und Schalen gerustes, fol. DXLIII.

The scapulo-coracoid arch, both elements of which retain the form of strong and thick vertebral and sternal ribs in the crocodile, is applied in the skeleton of that animal over the anterior thoracic hæmal arches. Viewed as a more robust hæmal arch, it is obviously out of place in reference to the rest of its vertebral segment. If we seek to determine that segment by the mode in which we restore to their centrums the less displaced neural arches in the sacrum of the bird (fig. 27, *n* 1–*n* 4), we proceed to examine the vertebræ before and behind the displaced arch with the view to discover the one which needs it in order to be made typically complete. Finding no centrum and neural arch without its pleurapophyses from the scapula to the pelvis, we give up our search in that direction; and in the opposite direction we find no vertebra without its ribs until we reach the occiput: there we have centrum and neural arch, with coalesced parapophyses—the elements answering to those included in the arch N 1, fig. *5*—but without the arch H 1; which arch can only be supplied, without destroying the typical completeness of antecedent cranial segments, by a restoration of the bones so–s2, to the place which they naturally occupy in the skeleton of the fish. And since anatomists are generally agreed to regard the bones so–s2 in the crocodile (fig. 22) as specially homologous with those so numbered in the fish (fig. *5*), we must conclude that they are likewise homologous in a higher sense; that in fig. *5* the scapulo-coracoid arch is in its natural or typical place, whereas in the crocodile it has been displaced for a special purpose. Thus, agreeably with a general principle, we perceive that as the lower vertebrate animal illustrates the closer adhesion to the archetype by the natural articulation of the scapulo-coracoid arch to the occiput, so the higher vertebrate manifests the superior influence of the antagonising power of adaptive modification by the removal of that arch from its proper segment.

The scapula retains the more common cylindrical long and slender rib-like form of the pleurapophysis in the chelonian reptiles, where, from the greater length of the neck, it has retrograded further than in the crocodile from its proper centrum, and is placed not upon, but within, an anterior thoracic hæmal arch, the pleurapophysis of which has, on the other hand, been expanded like a scapula.

If the arguments founded upon the relations of the scapulo-coracoid arch to the segments of the skeleton in osseous fishes and crocodilians be admitted to sustain the conclusion here drawn from them, that arch must be held to form the hæmal complement of the occipital vertebra in all animals. Bojanus, in illustrating his vertebral theory of the skull by the osteology of the *Emys Europæa*, thus defines the

"VERTEBRA OCCIPITALIS, SIVE CAPITIS PRIMA.

"Basis occipitis, seu *corpus* hujus vertebræ,

"Pars lateralis occipitis, sive *arcus*,

"Crista occipitalis, *processus spinosi* loco,

"Cornu majus hyoidis, *costæ vertebræ* occipitalis comparandum *."

He adds a dotted outline of the hyoid arch to complete the *vertebra occipitalis*, in tab. xli. fig. 32, B. 1 of his beautiful Monograph.

Supposing the special homology of the middle cornua of the hyoid of the chelonian, so represented and compared to ribs by Bojanus, with the stylo-, epi- and cerato-hyals of the fish (fig. *5*, 28, 29, 40) to have been correct, which the metamorphoses of the hyoid and branchial arches in the batrachians disprove, the singular and highly interesting change of position as well as shape of the true ceratohyals, during the same metamorphosis, prepares us to expect a retrogradation of the hyoid arch in respect to its proper centrum, in the

* Anatome Testudinis Europææ, fol. 1819, p. 44.

skulls of the air-breathing vertebrates. In the young tadpole the thick cartilaginous hyoidean arch * is suspended, as in fishes, from the tympanic pedicle: the slender hyoidean arch of the mature frog is suspended from the petrosal capsule †. The mandibular arch has, also, receded; and the scapular arch which, at its first appearance, was in close connection with the occiput, further retrogrades in the progress of the metamorphosis to the place where we find it in the skeleton of the adult frog.

The argument, therefore, may be summed up as follows. The position of the neurapophyses in the dorsal vertebræ of chelonians and in the sacral vertebræ of dinosaurians and birds, shows that a change of relative position in respect of other elements of the same vertebra may be one of the teleological modifications to which even the most constant and important elements are subject. Instead of viewing such shifted arches as independent individual parts, we trace their relation to the stationary elements of the vertebral segments—the centrums. Thus, commencing, for example, with the anterior of the sacral vertebræ of the ostrich, A in fig. 27, we observe that, besides supporting its own neural arch, it bears a small portion of that of the next vertebra: the third neural arch (n 1) has encroached further upon the centrum of the vertebra in advance; and thus, in respect to the neural arch (n 2), if it were viewed with the centrums, c 2 and c 1, upon which it equally rests, apart from the rest of the sacrum, it would appear to appertain equally to either, and be referable to the one in preference to the other quite gratuitously. Nevertheless n 2 is proved, by the intermediate changes in antecedent neural arches, to belong actually, and in no merely imaginary or transcendental sense, to c 2 altogether, and not to the segment of which c 1 is the centrum; and in tracing the modifications of those sacral vertebræ which follow c 2, we find n 4 to have regained nearly the whole of its centrum, c 4, and the normal relations of the elements are quite restored in the succeeding vertebra.

Now let us suppose the habits of the species to have required a more extensive displacement of the arch (n 2) and its appendages: if its formal characters as a neural arch were still retained beneath the adaptive development superadded to the adaptive dislocation, and if the segments before and behind the centrum c 2 were found complete, and that centrum alone wanting its neural arch; would the mere degree of modification in respect of relative position nullify the conclusion that the shifted arch appertained to such incomplete segment, and forbid that restoration to the typical condition, which no anatomist, it is presumed, will dispute in the case of n 2, c 2, fig. 27? No anthropotomist hesitates in pronouncing the exact vertebra to which the sixth ribs belong in the human skeleton. But, separate that costal arch with the two bodies and neural arches of the vertebræ with which it articulates, and to which of them it belonged would be as questionable as in the instance of the displaced neural arch in the bird's sacrum. The head of each rib is applied half to the upper centrum, half to the lower one: the upper border of the neck of the rib articulates with the upper neural arch, the tubercle with the diapophysis of the lower neural arch. If a naturalist, not conversant with the definitions of human anatomy, were shown this detached part of the human skeleton and were pressed to determine the proper centrum and neural arch of the hypothetically displaced costal element, the attempt might seem to him gratuitous: and to the question, to which of such centrums the rib exclusively (as to the pre-existing pattern) belonged? he

* Cuvier, Ossem. Foss. v. pt. ii. pl. 24, fig. 23, *a*.

† *Ib.* fig. 27, *a*:—an intermediate stage is shown at fig. 25. Dugés and Reichert confirm and further illustrate this change of position of the hyoidean arch.

might reply, to neither. And such, doubtless, would be the matter-of-fact answer most congenial to the character of mind which would limit its views to the specialities of the ribs as parts independent of any ideal archetype, or be unable or unwilling to push the consideration of their connections beyond the purposes apparently subserved thereby. A second anatomist might see in the more constant articulation of the costal tubercle with the transverse process, a character which would incline the balance in favour of the vertebra to which the transverse process belonged. A third anatomist might extend his comparisons to other ribs and centrums, and finding the lower centrum obtaining by degrees a greater proportion of the head of the rib, until the first and last ribs respectively wholly articulated to the centrum answering to the lower one in the case of the hypothetically detached sixth pair, he would conclude that such pair of ribs belonged essentially to the lower and not to the upper supporting centrum, and he would count accordingly such lower centrum with its neural arch, as the sixth of those vertebræ which are characterized as supporting ribs. The anthropotomist, in fact, in so counting and defining the dorsal vertebræ and ribs, admits unconsciously perhaps, an important principle in general homology, which pursued to its legitimate consequences and further applied, demonstrates that the scapula is the modified rib of that centrum and neural arch which he calls the 'occipital bone,' and that the change of place which chiefly masks that relation (for a very elementary acquaintance with comparative anatomy shows how little mere form and proportion affect the homological characters of bones) differs only in extent and not in kind from the modification which makes a minor amount of comparative observation requisite in order to determine the relation of the shifted sixth rib to its proper centrum.

With reference, therefore, to the occipital vertebra of the crocodile, if the comparatively well-developed and permanently distinct ribs of all the cervical vertebræ prove the scapular arch to belong to none of those segments, and, if it be wanting to complete the occipital segment, which it actually does complete in fishes, then the same conclusion must apply to the same arch in other animals, and we must regard the occipital vertebra of the tortoise as completed below by its scapulo-coracoid arch, and, not as Bojanus supposed, by its hyoidean arch*.

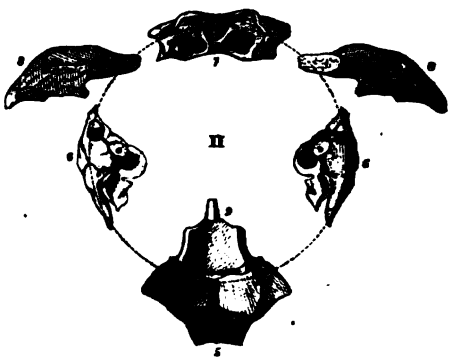
With these views of the general homology of the scapulo-coracoid arch, the embryologist will observe with less surprise its constant appearance in the first instance close to the occiput, and its equally constant primitive vertical position; however far back it may be subsequently removed, or to whatever extent it may be rotated, in the same progress to maturity, out of its original parallel direction with the more normal pleurapophyses.

Returning to the study of the crocodile's skull in reference to the vertebrate archetype, if we proceed to dislocate the next segment in advance of the occipital, we bring away in connection with the long base-bone, s and o, fig. 22, the bones connected by the double lines N II, N III, and by the

* Geoffroy St. Hilaire selected the opercular and subopercular bones to form the inverted arch of his seventh (occipital) cranial vertebra (Table III. and note 11), and took no account of the instructive natural connections and relative position of the hyoidean and scapular arches in fishes. With regard to the scapular arch, he alludes to its articulation with the skull in the lowest of the vertebrate classes as an 'amalgame inattendue' (Anatomie Philosophique, p. 481); and elsewhere describes it as a "disposition véritablement très singulière, et que le manque absolu de cou et une combinaison des pièces du sternum avec celles de la tête pouvoient seules rendre possible."—Annales du Muséum, ix. p. 361.
cation of the law of vegetative uniformity or repetition, and of the ratio of
and power to the grade of organization of the species, might have enabled
the true signification of the connection of the scapular arch in fishes.

curved arrows H II and H III. The relations of the superior series of bones as neural arches to the optic lobes and cerebrum are even less doubtful than in many fishes, by reason of the much smaller degree of independent ossification of the proper capsule of the acoustic labyrinth. Taking, then, the bones forming the arch N II, we find them, viewed from behind, to present the general arrangement shown in fig. 19. The hinder (basisphenoidal) portion of the bone 8 and 9 forms the *centrum*, and immediately supports the floor of the mesencephalon, or lobe of the third ventricle, being excavated for the pituitary prolongation of that cavity: it also sends a process downwards, repeating, like the basioccipital, the inferior exogenous spine of the centrums of the cervical vertebræ. The bones 6, 6 protecting the sides of the mesencephalon, and notched for the transmission of the trigeminal nerve, manifest the *neurapophysial* characters of the segment. As accessory functions they contribute, like the corresponding bones in fishes, to the formation of the ear-chamber. They have, however, a little retrograded in position (see fig. 9), resting below, in part, upon the occipital centrum, and supporting more of the spine of that centrum (8) than of their own (7); which is, however, formed of a single bone, and in so far manifests more of the normal character of the element completing the neural arch, as its crown or key-bone, than does the homologous divided and often divaricated bone in fishes. This and other analogous facts show that although the lowest vertebrate class adheres most, as a whole, to the archetype, yet that it can be recognised clearly and unequivocally only by patient study of its modifications in all classes: for even the lowest have special exigencies arising out of their sphere of existence calling for modifications of the type which are not present in other and higher classes. We shall find, indeed, that the connation of the basi- and pre-sphenoids ceases in mammals, and that they only coalesce in that class, being primitively distinct; so that the second cranial centrum (8) may be removed with its neural arch, in the fœtal quadruped (fig. 24) or human subject (25), without doing violence to nature by the use of the saw. The bones 8, 8, fig. 19, wedged between 6 and 7, here, also, manifest more of their *parapophysial* character than in fishes, inasmuch as they are excluded from the inner walls of the cranium, whilst they retain and manifest broadly their characters as outstanding processes for muscular attachment. But, besides affording ligamentous attachment to the hyoid arch (39, 40), they articulate largely with the proximal element (18) of the mandibular arch, whose backward displacement, in comparison with its more normal position in the fish's skull (fig. 5), is as clearly illustrated in the metamorphosis of the anourous batrachia, as is that of the hyoidean or scapular arches.

Fig. 19.



Disarticulated mesencephalic arch, viewed from behind: Crocodile.

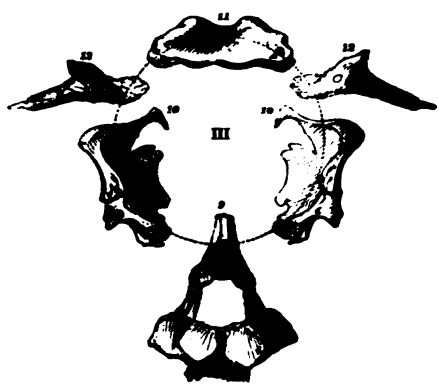
Referring, then, to the side view of the cranial vertebræ of the crocodile (fig. 22), we see the hæmal arch of the second or parietal vertebra in the hyoid (39, 40, 41) retaining so much of its embryonic dimensions as is required

by its restricted functions, and having no call for progressive growth in subserviency to a branchial respiration. It consists of a ligamentous stylohyal, its *pleurapophysis*, retaining the same primitive histological condition which obstructs the ordinary recognition of the same elements of the lumbar hæmal arches. The hæmopophyses and hæmal spine are, however, here as there, more advanced in respect of their tissue. The *hæmopophysis* is ossified like the so-called 'abdominal ribs,' and usually, like them, consists of two portions, having the special names of epihyal (39) and ceratohyal (40): the *hæmal spine* (41) retains its cartilaginous state like its homotypes in the abdomen: there they get the special name of 'linea alba' or abdominal sternum, here of 'basihyal.' With respect to formal modification, this element is chiefly remarkable in the crocodile for its broad expanse: it sustains the ascending valvular ridge at the base of the tongue, which, applying itself against the descending 'palatum molle,' constitutes an effectual barrier against the entry of water into the glottis from the mouth, whilst the crocodile is engaged in overcoming the struggles of a submerged and drowning prey.

There being no need of diverging appendages from the hyoidean arch in the crocodile, branchiostegal rays are not developed. The scapular arch is similarly simplified in *Anguis* and other serpentiform lizards; but, to those who recognise its true homology, its presence without a trace of its appendages, the fore-limbs, will create no more surprise, than the presence of the hyoidean arch without the branchiostegal fins or of the mandibular arch without the opercular fins.

On removing the neural arch of the parietal vertebra, with or without the section of the connate centrum (5), the bones completing, with the part (9), the corresponding arch of the frontal vertebra present the general arrangement shown in fig. 20.

Fig. 20.



Disarticulated prosencephalic arch, viewed from behind; Crocodile.

The compressed produced bone, 9, shown in natural connection with the bone 10 in fig. 9, notwithstanding its modified form, presents all the essential characters of the *centrum* of the arch: although it may have been developed exclusively from the capsule of the notochord, like the coalesced inferior parts of the cervical centrums in the silurus: there is no distinct ossicle answering to the central part of the centrum of the frontal vertebra, like 9′, fig. 5, in certain bony fishes. On the other hand, we find the *neurapophysial* characters of the orbito-sphenoids (10, 10) more largely and typically manifested in the crocodile: they are smoothly excavated within by the sides of the prosencephalon: they dismiss the great special-sense nerves of the eye by the notch (fig. and the motor nerves by the notch *s*: they show, however, the sa decey to change of position as the succeeding neurapophyses; for they support a greater proportion of their proper spine (11), they al port part of the succeeding spine (7), and rest below in part upon

rietal centrum (8). The *neural spine* of the frontal vertebra (11) retains its normal character as a single symmetrical bone, like the parietal spine, which it partly overlaps. It is much developed longitudinally, but more in the anterior, and less in the lateral direction than in most fishes.

One cannot contemplate the relative position of the frontal to the parietal and of the parietal to the supraoccipital, which is overlapped by the parietal and itself overlaps the flattened spine of the atlas, without a conviction of the serial homology of these single, median, imbricated bones, all completing arches above the neural axis, and each permanently distinct from the piers or haunches of the arch of which it forms the key-stone. In like manner the serial homology of those piers or neurapophyses, viz. the laminæ of the atlas, the exoccipitals, the alisphenoids and the orbitosphenoids, is equally unmistakeable. Nor can we close our eyes to the same serial relationship of the postfrontals (fig. 20, 12, 12) as parapophyses of their vertebra, with the mastoids (8) and the coalesced paroccipitals (4). The frontal *parapophysis*, 12, is wedged between the back part of the spine, 11, and the neurapophysis, 10: its outward process extends backwards and joins the next parapophysis (8); but, notwithstanding the retrogradation of the mandibular arch, it still receives a small part of its own *pleurapophysial* element (28). This element now manifests its typical unity: vegetative subdivision, much reduced in the batrachian reptiles, no more prevails in the development of the frontal pleurapophysis in any higher vertebrate. The serpents exhibit this element under the common form of a rib; longer, indeed, than are any of the pleurapophyses in the batrachian order; but it has so far retreated in serpents as to be exclusively attached to the parietal parapophysis, which is remarkably elongated and produced backwards, and suspends the long, slender, straight and simple frontal pleurapophysis (tympanic pedicle) vertically from its posterior extremity. In lacertians no. 28 is vertically suspended from no. 8, and, commonly also, from no. 27, which is continued from the backwardly produced parapophysis of the frontal vertebra (12) to that of the parietal vertebra (8) in most of this division of the Cuvierian order *Sauria*. In chelonians and crocodilians the diverging appendage of the maxillary arch (27) descends and applies itself to a large proportion of no. 28, down to its lower articular end, and contributes to fix and strengthen that bone, as well as the modified costal arch from which it diverges.

The condition of the shortening, expansion and fixation of the frontal pleurapophysis in crocodiles and chelonians is exemplified in the uses to which the modified hæmapophyses, completing that costal arch, are put. Tortoises crop the grass by the application of the trenchant horny plates of the under to those of the upper jaw: turtles equally need a fixed suspensory joint of the under jaw in the act of biting and dividing the tough sea-weeds. Crocodiles have the frontal hæmapophyses (mandibular rami) unusually long; supporting numerous large laniary teeth, and requiring a fixed and firm point of suspension in the violent actions to which they are put in retaining, and overcoming the struggles of their prey.

The teleological complication of the lower or distal elements of the arch in question (29–32, fig. 22) is carried further than in fishes: there was more need, in fact, for a combination of the greatest elasticity and strength with the least weight of bone* in the frontal hæmapophysis of the crocodile than in the frontal pleurapophysis of the fish (28 *a*–28 *d*, fig. 5).

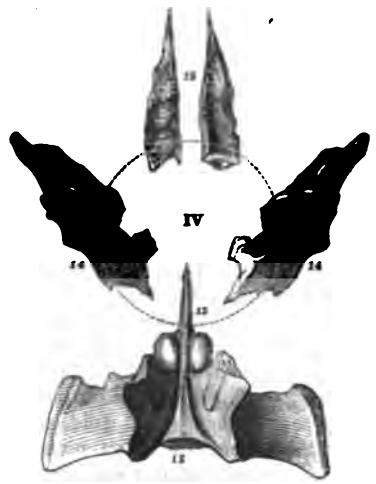
There, lastly, remain then in the skull of the crocodile the bones inter-

* Conybeare, Geol. Trans. 1821, p. 565. Buckland, Bridgewater Treatise, 1836, vol. i. p. 176. This author well illustrates the final purpose of the subdivision of the mandibular

sected by the lines N IV and the arrow H IV, with those numbered 26, 27, and 72, and we have to inquire whether through all the modifications which their extreme position subjects them to, we can still trace any evidence of their arrangement according to the vertebrate type.

A long and slender symmetrical grooved bone, like the ossified inferior half of the capsule of a notochord, is continued forwards from the centrum of the foregoing vertebra, and stands in the relation of a *centrum* (13) to the vertical plates of the bones 14, which expand as they rise into the broad and thick triangular plates with an exposed horizontal superior surface. The arch of which these form the piers, and to the anterior rhinencephalic prolongations traversing which arch they stand in the relation of *neurapophyses*, is completed by the two bones (12): which I, therefore, regard as a divided *neural spine*. In fishes we have seen that the corresponding element of the parietal vertebra was similarly divided, whilst the neural spine of the nasal vertebra was single: in the crocodile the reverse conditions prevail. In a species of alligator I have observed the bone 12 continued further forward, expanded, and divided at the middle line, the two divisions forming a small disc on the bony palate. The centrum of the nasal vertebra is divided longitudinally at the median line in batrachians, ophidians, and most lacertians; it is single in chelonians, but retains its cartilaginous state in some species (*Emys expansa*, *e. g.*). The neurapophyses (14, 14) transmit the olfactory nerves in all reptiles; but the ganglions are usually withdrawn backwards into the prosencephalic neural arch, leaving

Fig. 21.



Disarticulated rhinencephalic arch, with the anchylosed pterygoids (24) viewed from behind: Crocodile.

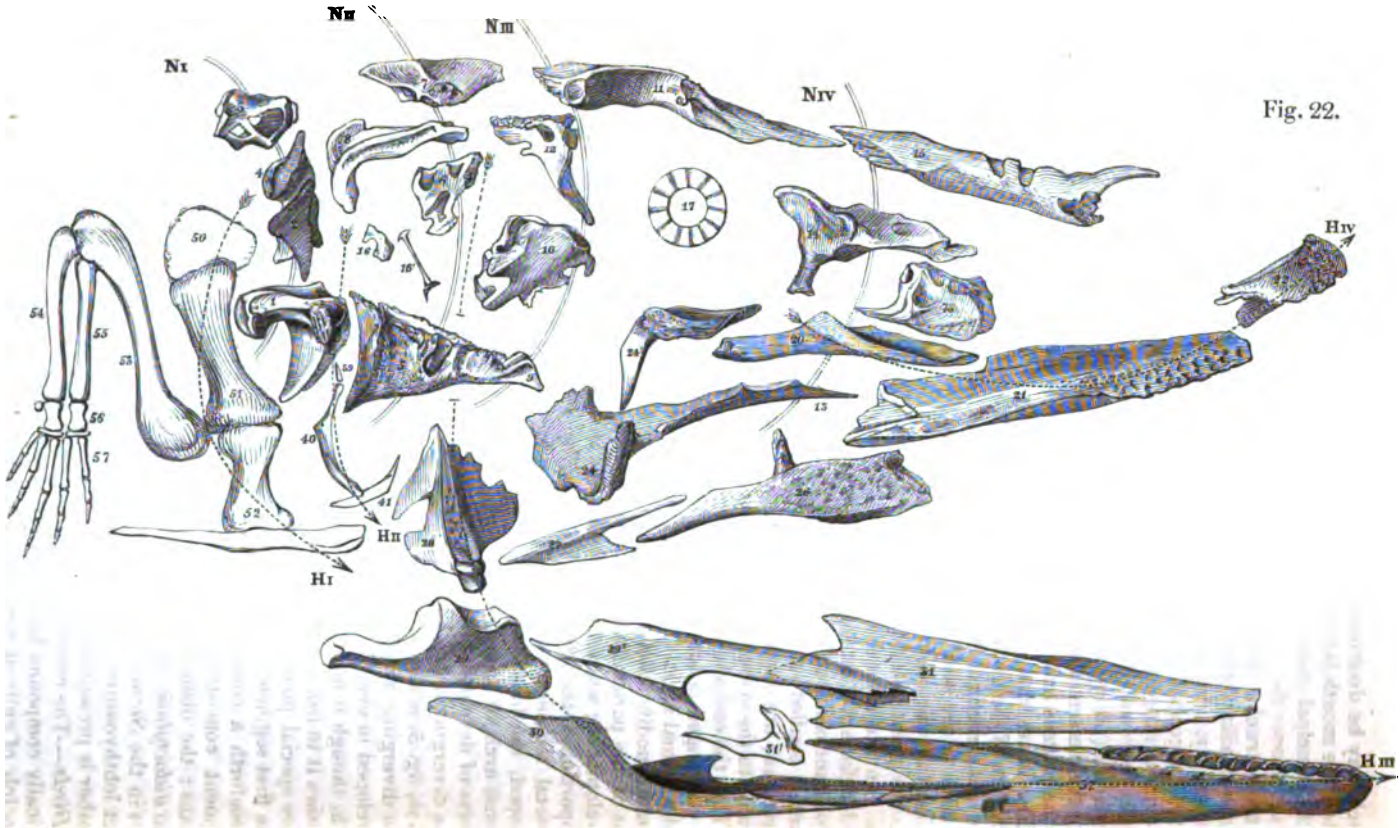
ramus in the recent and extinct saurians by pointing out the similarity of the structure to that adopted in binding together several parallel plates of elastic wood, or steel, to make a cross-bow; and also in setting together thin plates of steel in the springs of carriages. Dr. Buckland adds, "Those who have witnessed the shock given to the head of a crocodile by the act of snapping together its thin long jaws, must have seen how liable to fracture the lower jaw would be, were it composed of one bone only on each side."—*Ib.* p. 177. The same reasoning applies to the composite condition of the long tympanic pedicle in fishes. In each case the splicing and bracing together of thin flat bones of unequal length and of varying thickness affords compensation for the weakness and risk of fracture that would otherwise have attended the elongation of the snout. In the abdomen of the crocodile and plesiosaur the analogous composition of the hæmapophyses (abdominal ribs) allows of a slight change of length in the expansion and contraction of the walls of that cavity: and since amphibious reptiles, when on land, rest the whole weight of the abdomen directly upon the ground, the necessity of the modification for diminishing liability to fracture further appears. But what we are here chiefly concerned in is the evidence that the general homology of elementary parts of a natural segment is not affected by the modification of teleological composition of such parts. What happens to the hæmapophysial or inferior elements of the inverted arch in the abdominal segments of the crocodile also affects the [illegible] of a cranial hæmal arch; and the subdivision of the pleurapophyses of the sturgeon is repeated in the same elements of the cranial vertebræ in osseous

only the nerve-trunks to be protected by the nasal neurapophyses. These are, therefore, more approximated, and the anterior termination of the neural canal is much contracted; and, in the tailless batrachia, the nasal neurapophyses coalesce together.

We recognise in that element (20) of the fourth or foremost inverted arch of the crocodile's skull, which is in connection with the body (vomer, 13) and descending plates of the neurapophyses (prefrontals, 14) of the nasal vertebra, the proximal or *pleurapophysial* element of such arch; and the same repetition of the characteristic connections of the bone, 20, which enabled Cuvier and Geoffroy to recognise its special homology with the palatine bone in the fish, establishes its claim to be equally regarded in the crocodile as the pleurapophysis of its vertebral segment; although it now affords but a partial attachment to the bone 21, which forms the next element of the inverted arch. This bone, the *hæmapophysis*, has undergone a striking change in its proportions by development both in length and breadth: it is connected not only with no. 20 behind and with no. 22 before, but with the elongated spine, no. 15, of its own vertebra, and with the lacrymals, 72, above; with its fellow of the opposite side below, and with a well-developed proximal element, no. 26, of a strong diverging appendage behind. The *hæmal spine*, no. 22, is divided, and the arch is completed by the symphysial junction of the two halves at H IV. The nasal aperture or entry to the air-passages forms the span or area of the much-modified inverted arch constituting the upper jaw of the crocodile. The two proximal elements of the arch, nos. 20 and 21, continue to send outwards and backwards exogenous diverging processes; but they constitute a smaller proportion of the bones than in fishes, and both processes directly support distinct bones representing the *diverging appendage* of the arch, and serving to fix and attach it to the succeeding arch. The pleurapophysial appendage (pterygoid, 24) soon coalesces, however, with its fellow and with the centrum of its own vertebra (vomer, 13), and then expands to unite by a broad sutural surface with the coalesced centrums of the frontal and parietal vertebræ (9 and 5). A second osseous piece (ectopterygoid, 24′) diverges from the pleurapophysis external to the preceding and attaches it to the hæmapophysis, to the hæmapophysial appendage, and to the parapophysis of the frontal vertebra. The strong diverging ray from the hæmapophysis is teleologically subdivided into nos. 25 (malar) and 27 (squamosal), and firmly attaches the maxillary arch to the pleurapophysis (28) of the mandibular one.

In the chelonian reptiles the modifications of the nasal segment of the skull adhere pretty closely to the type of those in the crocodile; the centrum is more independent and better developed, but the divisions of the neural spine have coalesced with their neurapophyses: the diverging appendages, 25 and 27, are usually developed into broad and flat bones. In many lizards we find the nasal centrum divided but the neural spine single: the hæmal spine is, also, single, as a general rule, and sends upwards and backwards a process to join the neural spine, divide the area of the hæmal canal, and terminate the vertebral series anteriorly. The hæmapophysial diverging appendage commonly resumes its long and slender ray-like proportions, and joins the parapophyses of both frontal and parietal vertebræ as well as the proximal end of the pleurapophysis of the mandibular arch. In serpents both divisions of this appendage are absent (indicating the inferior character of the bones 25 and 27 in general homology), but the two parts of the pleurapophysial appendage, 24 and 24′, are retained and serve as levers in the movements of the maxillary arch. The spine of that hæmal arch is single, and commonly united only by lax and elastic ligaments with the hæmapophyses,

Fig. 22.



Disarticulated bones of the neural arches (N I. to IV.) and sense-capsules, and of the hæmal arches (H to IV) and appendages, of the skull of the crocodile (*Alligator lucius*).

which may be divaricated like the halves of the mandibular arch, so as to widen the mouth laterally; and this free suspension and incomplete closure of the principal costal arches of the cranium in serpents repeats in an interesting manner the characteristic free and open condition of all the costal arches of their trunk. In the genus *Tythlops* the diverging appendage of the palato-maxillary arch is reduced to the primitive condition of a long and slender ray. In anourous batrachians a long and slender backwardly produced exogenous process of the hæmapophysis (maxillary) joins a shorter advancing exogenous process of the distal division of the next pleurapophysis (tympanic): but in the tailed species the maxillary arch is fixed only by a broad (pterygoid) appendage; and both maxillary and premaxillary retain only their essential connections as forming the inferior arch of their segment. In the proteus and siren the pleurapophysis (maxillary) is almost obsolete.

The bones nos. 24, 24′, 26 and 27, being shown to be the least constant members of the group forming the nasal segment, and to form by their position and direction, the diverging appendages of the hæmal arch H IV, there remains in the skull of the crocodile only the bone 72, which by its position in front of the orbit and its relation to the lacrymal duct, is to be referred like the great anterior suborbital mucous bone in fishes to the dermal skeleton. In like manner the palpebral or supra-orbital scale-bones are to be excluded from the category of the pieces of the endoskeleton. The small and inconstant ossifications in the capsule of the organ of smell, together with the scarcely ossified sclerotals (17), the small petrosal, 16, and the columelliform stapes, 16′, are intercalated portions of sense-capsules and appendages referable to the system of the splanchnoskeleton.

Thus the endoskeletal system of bones of the head of the crocodile are naturally arranged in four segments, each composed of a centrum with a neural and a hæmal arch. The hæmal arches have been subjected, as in the trunk, to most modification; that of the occipital vertebra having been displaced; that of the parietal vertebra detached from its segment and arrested in its development; whilst that of the frontal vertebra is articulated in a very small proportion to the parapophysis of its own segment, but chiefly to that of the parietal segment, with paroccipital connections also; it is immensely developed, the hæmapophysial portion being the chief seat of extension. The hæmal arch of the nasal segment is also very large, but shows as much excess of development in breadth as that of the frontal vertebra in length. The diverging appendage is more complex than in fishes: one piece indeed, no. 25, fig. 5, is absent, but three others, 24′, 26 and 27, have been superadded. The diverging appendages of the frontal and parietal vertebræ cease to be developed in every class above that of fishes; but that of the occipital hæmal arch, though it no longer shows the luxuriant profusion of rays that distinguishes it in fishes, begins to assume a more fixed and definite character with more special powers and independent movements of its constituent parts. The first segment (53), doubtfully and obscurely recognizable in any fish, is henceforth a constant and important bone, and is always single: the next segment consists as exclusively of two bones, connate, indeed, in batrachians: the distal segment presents two jointed rays (digits) in the *Amphiuma didactylum*; three rays in *Amph. tridactylum* and the proteus and four rays in the *Siren lacertina*; it branched into as many as nine rays in the extinct ichthyosaurs; but they never exceed five in the existing saurians, which number is presented by this appendage in the crocodile (57, fig. 22.)

Birds.—The cranium of the bird offers the extremest instance of a homologically compound bone, and its development the clearest evidence of that principle of unity of composition which lies at the bottom of all the modifica-

tions of the cephalic division of the vertebrate endoskeleton. Although, as a general rule, the separate cranial bones can be discerned only at a very early period, yet in those birds in which the power of flight is abrogated the indications of the primitive centres of ossification endure longer, and in the species here selected for the illustration of the cranial segments (fig. 23) the constituent bones of the skull, though figured of their natural size, have, with the exception of the basioccipital, 1, and basisphenoid, 3, and the two bones, 6 and 8, which coalesce with the petrosal, 16, been separated by maceration merely. I may remark, however, that in all birds, certain bones, which coalesce with others in the cranium of most mammals, always retain their primitive individuality; the tympanic (28) and the pterygoid (24) for example.

The hindmost segment of the cranium (N 1, fig. 23) so closely repeats the characters of the epencephalic neural arch of the crocodile (fig. 18), as to render a separate and full view of it unnecessary for the illustration of its vertebral character. The basioccipital (1) still developes the major part of the single articular condyle, and sends down a process, more marked in the struthious genera, and especially the dinornis, than in most other birds: in all respects this primitively distinct bone retains the character of the *centrum* of its vertebra.

The exoccipitals, 12, contributing somewhat more to the occipital condyle than in the crocodile, develope, as in that reptile, the paroccipital (24) as an outstanding exogenous ridge or process: but it is lower in position than in the crocodile: the proper *neurapophysial* characters of no. 2 are fully maintained. The supraoccipital (3) now begins to manifest more strongly the flattening and development in breadth, by which the spinous elements lose the formal character from which their name originated, and are converted from long into flat bones. We saw the first step in this most common of the changes to which one and the same endoskeletal element is subject, in the detached neural spine of the atlas of the crocodile: that of the occipital vertebra of the same animal presented another stage in the metamorphosis: we have a third degree in the bird, and the extreme of expansion is attained in the human subject (fig. 25, 3), where the spine is sometimes developed, like that of the parietal vertebra, from two centres. But the arrested steps in this strange change of form and proportion demonstrate the essential nature of the part, as the neural arch, whilst the constancy of the characters of connexion is shown by this crown of the arch of the occipital vertebra having the exoccipitals as its piers or haunches from the fish to the human subject. It always protects the cerebellum; is absent in the frog where this organ is a mere rudiment; and is present in the crocodile in the ratio of the superior size of the cerebellum. The further development of the cerebellum is the condition of the superior breadth of the spine or crown of the epencephalic arch in the bird.

The arguments that determined the nature and displacement of the hæmal arch of the occipital vertebra in the crocodile apply with equal force to that in the bird. The extent of the displacement, it is true, has been greater: not seven, but seven-and-twenty vertebræ may intervene between the place of the scapulo-coracoid arch and the remainder of its proper segment constituting the occipital region of the simple cranial box in the bird. But this difference of extent ought no more to mask the real relationship of such costal arch to its centrum, than the degree of development of the spine of the occipital vertebra affects the general homology of that element.

In the ostrich, and other struthious birds, the hæmal arch of the occipital vertebra has retained much of its embryonic proportions. The *pleurapo-*

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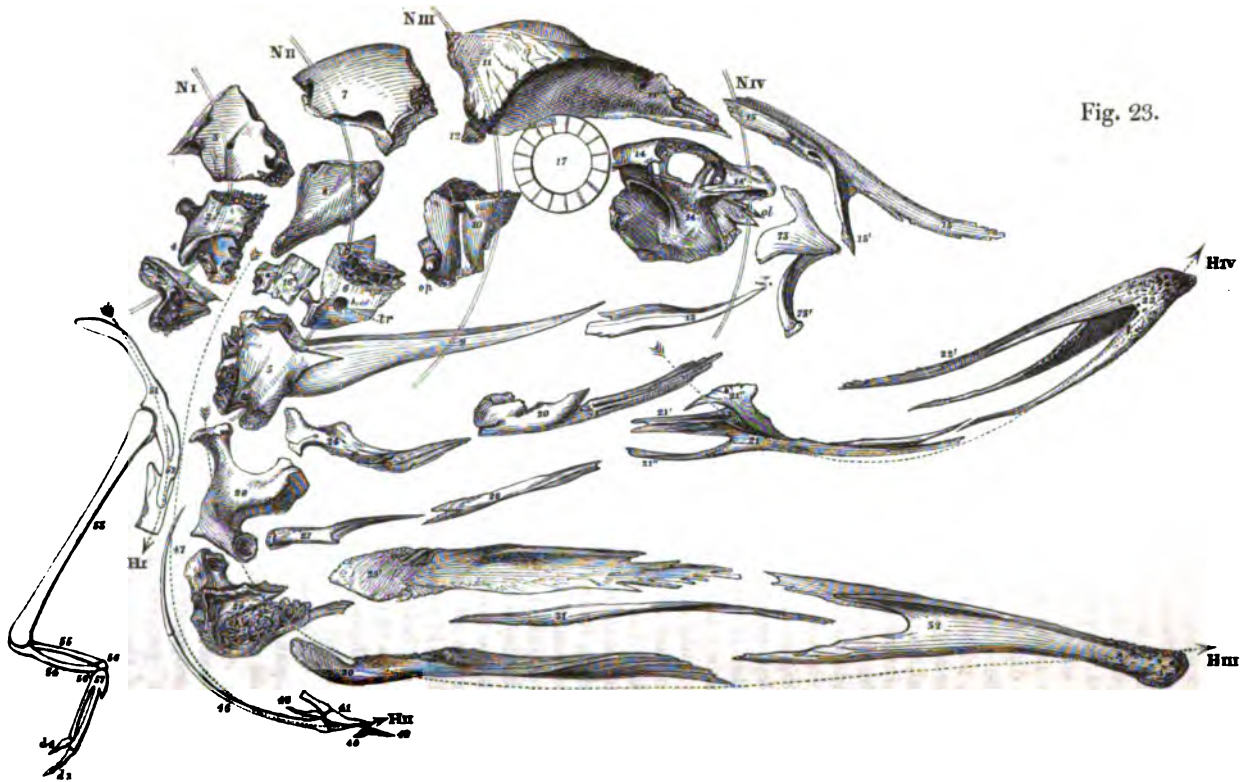
Fig. 23.



Disarticulated bones of the neural arches (N I to IV) and sense-capsules, and of the hæmal arches (H I to IV) and appendages, of the skull of the ostrich (*Struthio camelus*).

physial part (51) has, also, retained its slender rib-like form* ; it has coalesced with the *hæmapophysis* (52), and the inverted arch is completed, as in the crocodile, by a hæmal spine, as much modified in form by flattening and expansion as is the neural spine represented by the supraoccipital (3). The diverging appendage of the occipito-hæmal arch also retains much of its primitive simple character: a long and slender bone (52) supports two rays (54, 55), and there is an attempt at three at 57, of which one is short, atrophied and anchylosed to the rest. In the two small bones (56, 56) interposed between this and the preceding segment, we recognise the special homologues of the carpal series in the crocodile and fish: in 54 we have the ulna, in 55 the radius, in 53 the humerus, in 57 the metacarpus; in *d* 3 and *d* 4 the rudiments of the digits so numbered in the crocodile (fig. 22) and the mammal (fig. 24). The evidences of the unity of plan in the construction of the scapular limb, whether it be an arm with the prehensile hand, a hoofed foreleg, a wing, or a fin, are admitted by all; the same scapula, humerus, antibrachial, carpal, metacarpal and phalangial bones are readily recognised by the tyro in comparative osteology in the ape, the horse, the whale, the bird, the tortoise and the crocodile. The beautiful simplicity of the fundamental basis of all these adaptations of structure is descanted upon in all our popular teleological treatises. But the higher law governing the existence of these special homologies has attracted little attention in this country. Yet the inquiry into that more general principle of conformity to type according to which it has pleased the Creator of organic forms to restrict the manifestations of the variety of proportion and shape and substance and even relative position of the limbs requisite for the various tasks assigned to the vertebrate species, is one that by no means transcends the scope of the comparative anatomist. And the conclusion to which my comparisons have conducted me is, that one and the same element, viz. the diverging appendage of the occipital vertebra, forms the seat or substratum of all the adaptive modifications of the part called 'anterior' or 'superior extremity.'

The second segment of the skull has for its *central* element a bone (fig. 23, 8), which in the bird, as in other oviparа, is connate with that (9) which stands in the same relation to the third cranial segment; the proof of the natural distinction of these segments is given by the neural, N II, N III, and hæmal, H II, H III, arches. Probably the circumstance of the bodies of those vertebræ being formed by ossifications of the fibrous capsule of the notochord, representing the external or cortical parts only of such centrums, may be the condition, or a favourable physical cause of such connation. The neural arch of the parietal vertebra retains the same characters which it first manifested in fishes. Besides the *neurapophyses* (6) impressed by the mesencephalic ganglia and transmitting the trigeminal nerves, besides the vastly expanded and again, as in fishes, divided neural spine (7), the *parapophysis* (8) is independently developed. It is of large proportional size; and, owing to the raised dome of the neural arch, is relatively lower in position than in the crocodile; it sends downwards and outwards an unusually long 'mastoid' process, and forms a large proportion of the outer wall of the chamber of the internal ear with the bony capsule of which it speedily coalesces.

The hæmal arch of the parietal vertebra (H II) is more reduced than in the crocodile, and owes much of its apparently typical character to the retention of the thyrohyals (46, 47) borrowed from the branchial arches of the

* The very common modification of form which this element undergoes in becoming expanded into the broad scapula of man and other mammalia, appears to have influenced Oken in his idea of that bone being the homologue of a congeries of ribs.

visceral system, which are feebly and transitorily manifested in the embryo bird. These spurious cornua project freely or are freely suspended, and are the subjects of singular and excessive development, as has been exemplified in the chapter on Special Homology.

The bones (10) of the third neural arch protect a smaller proportion of the prosencephalon than in the crocodile, but maintain their *neurapophysial* relation to it and to the optic nerves: the *neural spines* (11) cover a larger proportion of the hemispheres, and, with their homotypes (7), exhibit a marked increase of development in conformity with that of the cerebral centres protected by their respective arches. The *parapophysis* of the frontal vertebra (12) is relatively smaller in the bird than in the cold-blooded vertebrates, and is rarely ossified from an independent centre; but I have seen this in the emeu, and it appears to have been constantly an autogenous element in the dinornis. The hæmal arch of the frontal vertebra has been transferred backwards to the parietal one; its *pleurapophysis* (28), which is simple, as in the crocodile, articulating exclusively with the parietal parapophysis (8), though this in some birds unites with that of the frontal vertebra. In the young ostrich and many other birds traces of the composite character of the *hæmapophysis* are long extant; and bear obviously a homological relation to the teleologically compound character of the element in the crocodile: for the pieces, nos. 29, 29′, 30′ and 31 ultimately, and in most birds early, coalesce with each other and with the *hæmal spine* (22), the halves of which are confluent at the symphysis.

The *centrum* (13) of the nasal vertebra is always single, and, when it does not remain distinct, coalesces with the neurapophyses, 14, and pleurapophyses, 26, of its own segment, and sometimes, also, with the rostral production of the frontal centrum (9): it is elongated and pointed at its free termination, and deeply grooved above where it receives the above-named rostrum; indicating by both its form and position that it owes its existence, as bone, to the ossification of the outer capsule of the anterior end of the notochord. In the ostrich the long presphenoidal rostrum intervenes between the vomer (13) and prefrontals (14). These latter bones manifest, however, as has been shown in the paragraph on their special homology (p. 214), all the essential *neurapophysial* relations to the rhinencephalon and olfactory nerves: but they early coalesce together, or are connate, as in the tailless batrachians. The *neural spine* (15) is divided along the middle line; but in most birds the suture becomes obliterated and the spine coalesces with its neurapophyses, with the frontal spine and with those parts of the hæmal arch of the nasal vertebra with which it comes in contact.

The *pleurapophyses* (fig. 23, 26) of this inverted arch retain their typical connections with the nasal centrum and neurapophyses at one end, and with the hæmapophysis (21) at the other end, and they also support the constant element of the diverging appendage of the arch, no. 24. The *hæmapophysis* (21) resumes in birds more of its normal proportions and elongated slender form: but the *hæmal spine* (22) is largely developed though undivided, and sends upwards and backwards from the part corresponding to the symphysis of the spine, when this element is divided, a long pointed process (22′), which joins and usually coalesces with the neural spine (15) and divides the anterior outlet of the hæmal canal into two apertures called the nostrils. The modification of the inferior arch of the nasal vertebra in the lizard tribe is here repeated. The pleurapophysial *appendage*, 24, connects the palato-maxillary arch with 29, and in the ostrich and a few other birds, also with 5: the second or hæmapophysial ray of the diverging appendage is developed in all birds, as in the squamate saurians; combining the movements

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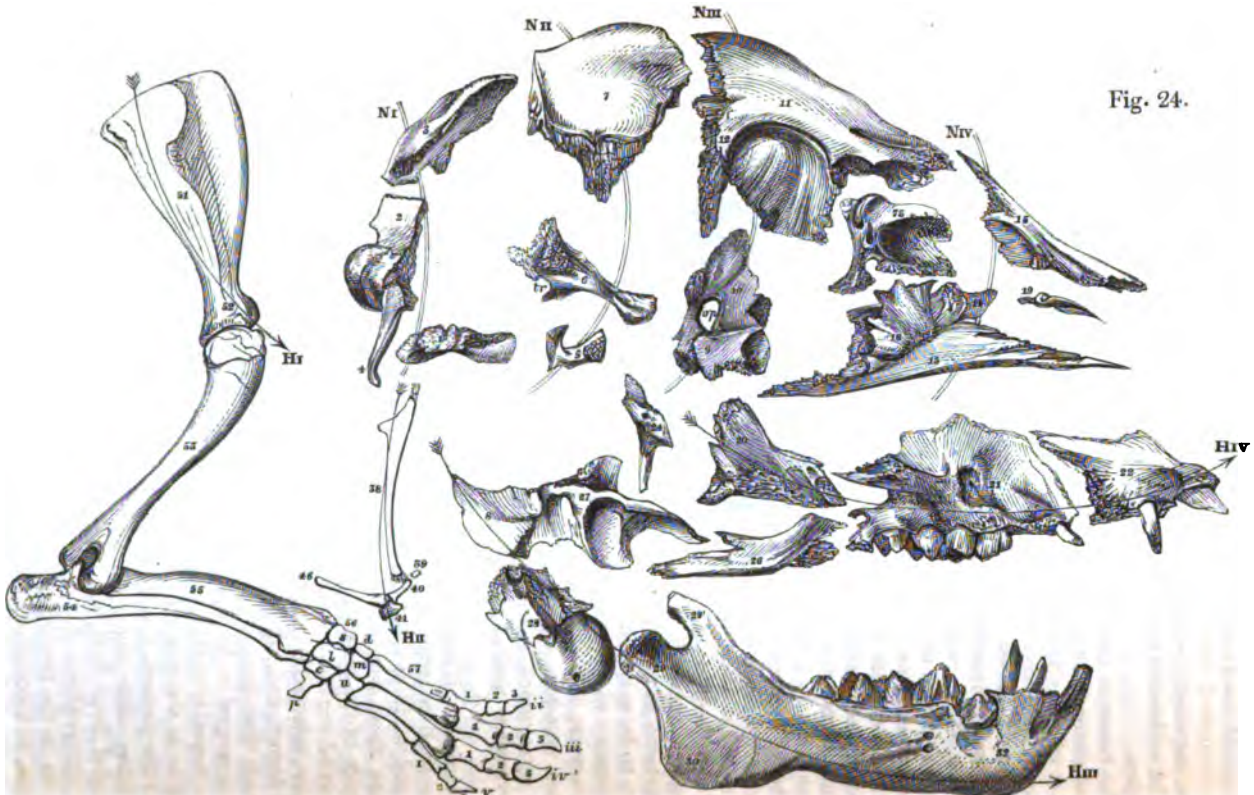
Fig. 24.



Disarticulated bones of the neural (N 1 to 1v) and haemal (H 1 to 1v) arches, and appendages, of the skull of a hog (*Sus Scrofa*).

of the hæmal arch of the nasal vertebra with that of the frontal vertebra, and consisting of the two styliform ossicles (26 and 27) which extend from the hæmapophysis, 21, 21″, to the pleurapophysis, 28: the essential relationship of the compound ray, 26 and 27, with the nasal vertebra, is indicated by their becoming confluent with its hæmapophysis (at 22″), whilst they always maintain an arthrodial articulation with the pleurapophysis (28) of the succeeding vertebra.

The bones of the splanchno-skeleton intercalated with the segments of the endoskeleton in the bird's skull are the petrosal (16), between the neural arches of the occipital and parietal vertebra, early coalescing with the elements of those vertebræ with which it comes in contact: the sclerotals (17), interposed between the frontal and nasal neural arches: and the thyro-hyals (17), retained in connection with the debris of the hæmal arch of the parietal vertebra, H II. The olfactory capsule remains cartilaginous. The dermal bone (72) is well-developed and constant: a second supraorbital dermal bone is occasionally present. All the endoskeletal bones manifest, under every adaptive modification, the segmental arrangement, and it is difficult to contemplate the repetition of the arrangement of the cranial bones around the primary segments of the encephalon in the series of arches closed respectively by the bones N I, N II, N III, N IV, together with that of the corresponding number of arches closed below, at H IV, H III, H II and H I, without a conviction that the type illustrated in fig. 15 is that upon which these segments of the skull have been constructed. This conclusion might seem forced, in respect to the occipital vertebra, were its displaced hæmal arch and appendages to be viewed without reference to their relative position and connections in the lower vertebrate classes; but it will be confirmed and shown to be agreeable to nature and to the recognised kinds and grades of modification to which the elements of one and the same vertebra are subject, by observing in the young bird the distinct pleurapophysial elements of those cervical vertebræ, beyond which the corresponding elements of the occiput have retrograded, in obedience to the functions which the hæmal arch of that vertebra and its appendages are destined to perform in the feathered class.

Mammals.—If the foregoing views of the general homology of the bones of the skull be agreeable to their essential nature, we should expect that the new and additional modifications, in the mammalian class, which tend to obscure those relations would be seated in the appendages and peripheral elements of the endoskeletal segments, or in the capsules and appendages of the special organs of sense.

I have selected with a view to testing such anticipation the skull of a young pachyderm*, and, after successively disarticulating the segments in the order in which they have been previously described, I have given a side view of them arranged in correspondence with the figures 23, 22, and 5. (Fig. 24.)

The neural arch of the occipital vertebra, N I, agrees with that of the bird and crocodile in the coalescence of the *parapophysis*, 4, with the *neurapophysis*, 2; but the process, 4, now descends from the lower part of the arch, and, as in many other mammals, is of great length. An articular condyle is also developed from each neurapophysis which articulates with the concave anterior zygapophysis of the atlas, and is the homotype of the posterior zygapophysis in the trunk-vertebræ. The centrum (1) is reduced, like that of the atlas, to a compressed plate, and its hinder articular surface is not more

* The skull of the ruminant is perhaps still better adapted to demonstrate the vertebral relations of the cranial bones: that of the sheep is the subject of the diagram for this purpose in the concluding volume of my 'Hunterian Lectures.'

developed than is the front one of the centrum of the atlas, with which, indeed, it is loosely connected by ligament. The expanse of the occipital spine, s, has been governed, agreeably with a foregoing remark, by the superior development of the cerebellum.

The hæmal arch of the occipital vertebra is represented, like those of the cervical vertebra, by the *pleurapophysial* elements only (51); but these, in most mammals, are developed into broad triangular plates with outstanding processes: that called 'spine' and 'acromion' is exogenous; but that called 'coracoid' is always developed from an independent osseous centre (a rudimental representative of the *hæmapophysis*, 52), which coalesces with the pleurapophysis in mammalia, and only attains its normal proportions, completing the arch with the hæmal spine (episternum) in the monotremes.

In many mammals the arch is completed by bones, which are, apparently, the hæmapophyses of the atlas, *e. g.* in man (fig. 25, 52′), which have followed the occipital hæmal arch in its backward displacement, but not quite to the same extent.

The diverging appendage, though retaining the general features of its primitive radiated form, has been the seat of great development and much modification and adjustment of its different subdivisions (53–57) in relation to the locomotive office it is now called upon to perform.

With the exception of this excess of development of the appendage, the defective development and displacement of the hæmal arch, and the coalescence of the parapophyses in the neural arch, there are few points of resemblance which are not sufficiently salient between the segment N 1, H 1 in the mammal, and that so marked in the fish (fig. 5). And, if the interpretation of the more normal condition of this segment in the lower vertebrate, according to the archetypal vertebra, fig. 15, be accepted, then the explanation of the nature of the modifications of the special homologues of the constituents of the occipital segment by which that archetype is masked in the mammal, may be confidently left to the judgement of the unbiassed student of homological anatomy.

In commencing his comparisons of the second segment of the skull with the typical vertebra, he will be unexpectedly gratified by finding, in the immature mammal, the *centrum*, 5, naturally distinct, and the hæmal arch, H II, retaining its natural connections with the rest of the segment, and by means of a more complete development of the pleurapophyses (38) than in any of the inferior air-breathing vertebrates. He may now separate, without artificial division of any compound bone, the entire parietal segment, but he brings away with it the petrified capsule of the acoustic organ, and the anchylosed distal piece (27) of the maxillary appendage, which more or less encumbers and conceals the typical character of the neural arch of the parietal vertebra in every mammal: least so, however, in the monotremes and ruminants. The *neurapophyses* (6) of the parietal vertebra, like the mesencephalic segment of the brain, are but little more developed in mammals than in the cold-blooded classes: they are notched in the hog and perforated in the sheep by the larger divisions of the trigeminal, and they send down an exogenous process, which articulates and sometimes coalesces with the appendage (24) of the palato-maxillary arch. The *neural spine* (7), always developed from two centres, often vastly expanded, and sometimes complicated with a third intercalary or interparietal osseous piece, is occasionally uplifted and removed from its neurapophyses by the interposed squamous expansion of the bone 27; but this, which reminds one of the occasional separation of the neural arch from the centrum of the atlas in fishes, is a rare modification in the mammalian class. A still rarer one is the separation of the halves of the parieto-neural spine

from each other by the extension and mutual junction at the median line of the occipital and frontal spines. A specimen of this, in a species of *Cebus*, which repeats the common modification of the parts in fishes, is preserved in the museum of the Royal College of Surgeons. The *parapophysis* (3) always commences as an autogenous element by a distinct centre of ossification, as shown in the human fœtus, fig. 11, 3; it speedily coalesces with the petrosal, but otherwise retains its individuality in some of the lower mammals, as *e. g.* in the echidna (fig. 12, 3): or it coalesces with the curtailed frontal pleurapophysis 28, or with the maxillary appendage 27, or with both these and the pleurapophysis of its own vertebra (38), when the complex 'temporal bone' of anthropotomy is the result. In most mammals the *pleurapophysis* (38) retains its primitive independency and rib-like form, with usually the 'head' and 'tubercle'; but by reason of its arrested growth it has been called 'styloid' bone or process. Sometimes it is separated from the short *hæmapophysis*, 46, by a long ligamentous tract, sometimes it is immediately articulated with it, or by an intervening piece. The *hæmal spine*, 41, is usually small, but thick and always single. The rudiments of hypobranchial elements (46) are retained as diverging appendages of the parieto-hæmal arch in all mammals, and have received the special names of 'posterior cornua,' or 'thyrohyals,' from their subservient relationship to the larynx.

In the frontal segment the *centrum*, 9, and *neurapophyses*, 10, very early coalesce. Two separate osseous centres mark out the body (fig. 26, C, 9), and each neurapophysis has two distinct centres (*ib.* 10, 10), the optic foramina (*op*) being first surrounded by the course of the ossification from these points. The superior development of the neurapophysial plates (10), as compared with those of the parietal vertebra (6), in most mammals, harmonizes with the greater development of the prosencephalon; but the chief bulk of this segment of the brain is protected by the expanded spines of the frontal (11) and parietal (7) vertebræ, and by the intercalated squamosals (27). And the appendicular piece (27) not only usurps some of the functions of the proper cranial neurapophyses, but, likewise, the normal office of the frontal pleurapophysis (28), in the support, viz. of the distal elements of the hæmal arch (29, 32), which now articulate directly with 27, in place of 28 as in all oviparous vertebrates. The true *pleurapophysis* of the frontal vertebra (28) is almost restricted in the mammalian class to functions in subserviency to the organ of hearing, is sometimes swollen into a large bulla ossea, like the parapophyses and pleurapophyses of the cervical vertebræ of *Cobitis*; it is sometimes produced into a long auditory tube, and sometimes reduced to the ring supporting the tympanic membrane. Yet, under all these changes, since its special homology is demonstrable with 28 in the bird (fig. 23) and crocodile (fig. 22) as well as with the teleologically compound bone, 28 *a*, *b*, *c*, *d*, in the fish (fig. 5), so likewise must its general homology, which is so plainly manifested in the fish, be equally recognised. The frontal *hæmapophysis* (fig. 24, 29, 30), and the corresponding half of the *hæmal spine* (*ib.* 32) are connate on each side in all mammals, and become confluent at H III, in most. The hæmal arch of the frontal segment of the skull, as in other air-breathing vertebrates, has no diverging appendage, unless the tympanic otosteals be so regarded, an idea which is not borne out by their development.

The nasal segment (N IV, H IV) is chiefly complicated by the confluence of parts of the enormously developed olfactory capsules (18) in the mammalian class, and its typical character is masked by the compression and mutual coalescence of the *neurapophyses*, 14. The *centrum* is usually much elongated, as at 13, and soon coalesces with both *neurapophyses* (14) and nasal capsules in the hog. The *neural spine* (15) is usually divided, but is sometimes single,

e. g. in *Simia*. In the rhinoceros it supports a dermal spine or horn. The *pleurapophysis* (20) or proximal element of the hæmal arch of the nasal vertebra has its real character and import almost concealed by the excessive development of the second element of the arch (21), which resumes in mammals all those extensive collateral connections which it presented in the crocodile; and to which are sometimes added attachments to the expanded spine of the frontal vertebra, as well as to that of its own segment. The pleurapophysis however, besides its normal attachment to its centrum, 13, sends up a process to the orbit, in order to effect a junction with its neurapophysis which sometimes appears there, as the 'os planum' of anthropotomy. The *hæmal spine* (22) is developed in two moieties, which never coalesce together, although, in the higher apes, and at a very early period in man, each half coalesces with the hæmapophysis, and repeats the simple character of the corresponding elements (rami) of the succeeding (mandibular) arch.

The *appendicular* element (24) which diverges from the pleurapophysis (20), contributes to fix and strengthen the palato-maxillary arch by attaching it to the descending process of the parietal centrum (5); with which, in most mammals, it ultimately coalesces. The other elements of the diverging member of the arch correspond in number and in the point of their divergence with those in birds, chelonians and crocodiles. They are two in number, succeeding each other, and both become the seat of that expansive development which is followed by the multiplication of their points of connection; thus the proximal piece ('malar' 26) articulates in the hog not only with the hæmapophysis (21) from which it diverges, but likewise with the muco-dermal bone, 73. The distal piece of the appendage (squamosal, 27) expands as it diverges, and fixes the naso-hæmal arch not only to the frontal pleurapophysis (28), but also to the frontal, parietal and occipital neurapophyses and spines: it also affords, in the hog, as in other mammals, an articular surface to the frontal hæmapophysis (29).

The development of an osseous centre in the cartilage of the snout of the hog, and the homologous 'prenasal' ossicle in certain fishes, the carp, *e. g.*, might be regarded as rudiments of terminal abortive segments more anterior than the nasal vertebra. The multiplied points of ossification in the vomer have been, also, deemed indications of that bone being, like the vomerine coccygeal bone in birds, a coalescence of several vertebral bodies. Of course, *à priori*, the segments in the cranial region of the endoskeleton might as reasonably be expected to vary in number in different species, as the segments in the thoracic or sacral regions. I have not, however, been able to determine clear and satisfactory representatives of more than four vertebræ in the skull of any animal; and the special ossifications in the nasal cartilages appear to me to belong to the same category of osseous parts, as the palpebral bones in certain crocodiles and the otosteals.

Man.—Arriving, finally, in the ascensive survey and comparison of the archetypal relations of the bones of the vertebrate skull, at Man, the highest and most modified of all organic forms, in which the dominion of the controlling and specially adapting force over the lower tendency to type and vegetative repetition is manifested in the strongest characters, we, nevertheless, find the vertebrate pattern so obviously retained, and the mammalian modification of it, as illustrated in the preceding paragraph and diagram, so closely adhered to, as to call for a brief notice only of those developments of the common elements which impress upon the human skull its characteristic form and proportions.

The neural arch of the occipital vertebra differs from that of the hog by a much greater development of the *neural spine* (fig. 25, 3) and a much less

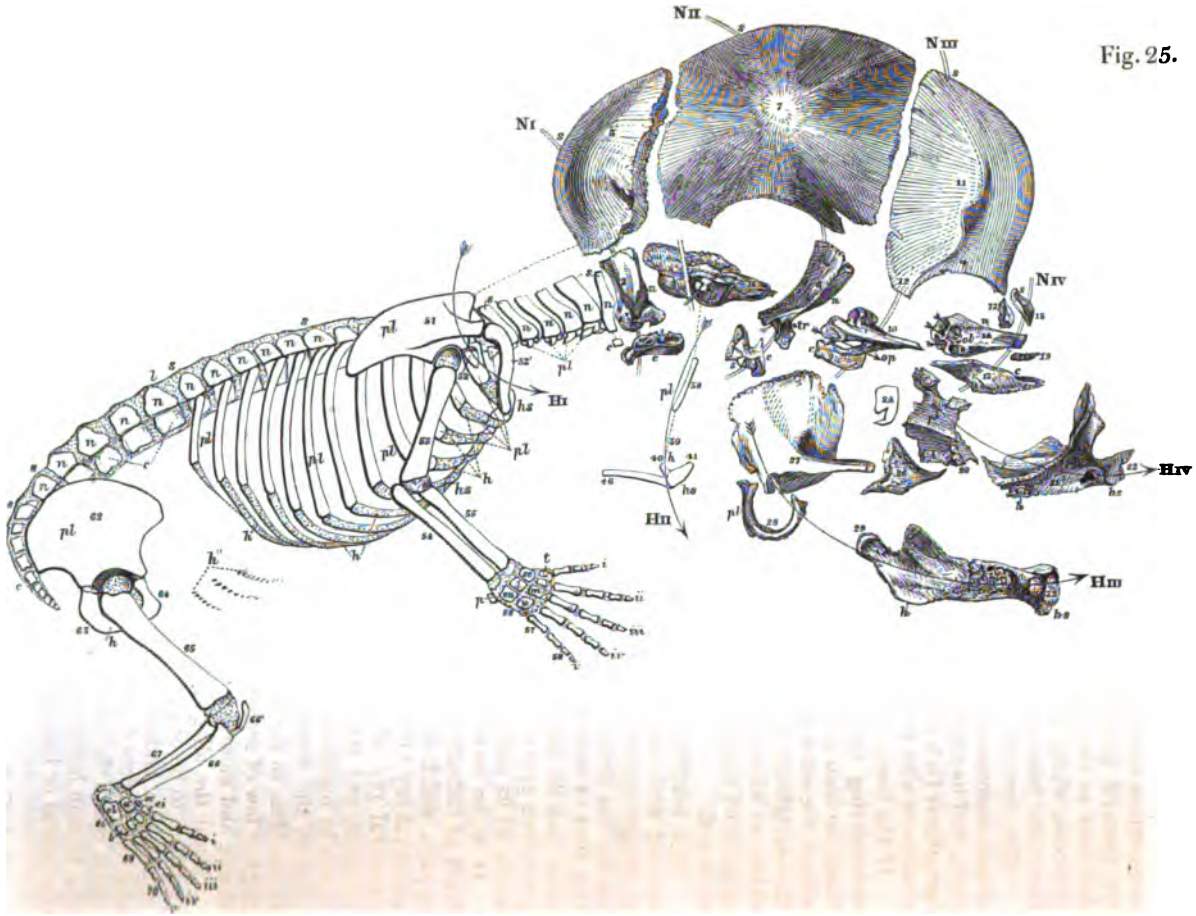


Fig. 25.

development of the parapophysis. This, as in other mammals, is not only an exogenous process of the *neurapophysis*, 2, but is commonly reduced to a mere "scabrous ridge extended from the middle of the condyle towards the root of the mastoid process" (Monro, *l. c.* p. 72)—the "eminentia aspera musculum rectum lateralem excipiens" of Soemmerring: the knowledge of its general homology, however, makes quite intelligible and gives its true interest to the occasional development of this ridge into a 'paramastoid' process, which now, however, projects, like the true 'mastoid,' downwards from the basal aspect of the cranium (*ante*, p. 204).

The occipital *pleurapophysis*, *pl*, 51, shows the same displacement as in other mammals, but is still more expanded in the direction of the trunk's axis, and its exogenous (acromial) process is still more developed. The *hæmapophysis* (52), originally distinct, has its development checked and speedily coalesces with the pleurapophysis.

If the bone 52′ be the special homologue of the bone, 56, in the fish,—and considering the backward displacement of 51 and 52, its anterior position to them in man is no valid argument against the determination,—then we may adopt the same general homology, and regard the clavicle, in its relations to the vertebrate archetype, as the displaced hæmapophysial element of the atlas, to which segment its true relative position is shown in the same low organized class in which the typical position of the scapular arch is likewise retained.

The adaptive developments of the radiated appendage of the occipital hæmal arch reach their maximum in man, and the distal segment of the appendage constitutes in him an organ which the greatest of ancient philosophers has defined as the "fit instrument of the rational soul;" and which the first of modern physiologists has described "as belonging exclusively to man—as the part to which the whole frame must conform"*. And these expressions give no exaggerated idea of the exquisite mechanism and adjustment of its parts.

It is no mere transcendental dream, but true knowledge and legitimate fruit of inductive research, that clear insight into the essential nature of the organ, which is acquired by tracing it step by step from the unbranched pectoral ray of the protopterus to the equally small and slender but bifid pectoral ray of the amphiume, thence to the similar but trifid ray of the proteus, and through the progressively superadded structures and perfections in higher reptiles and in mammals. If the special homology of each part of the diverging appendage and its supporting arch are recognisable from Man to the fish, shall we close the mind's eye to the evidences of that higher law of archetypal conformity on which the very power of tracing the lower and more special correspondences depend?

Until the alleged facts (p. 285) are disproved, demonstrating change of position to be one of the modifications by which parts of a natural and recognisable endoskeletal segment are adapted to special offices, and until the conclusions (p. 286) deduced from those facts are shown to be fallacious, I must retain the conviction that, in their relation to the vertebrate archetype, the human hands and arms are parts of the head—diverging appendages of the costal or hæmal arch of the occipital segment of the skull†.

* Bell (Sir Charles), "The Hand." Bridgewater Treatise, 1833, pp. 16, 18.
Μόνον δὲ καὶ ἀμφιδέξιον γίγνεται τῶν ἄλλων ζώων ἄνθρωπος.—Aristotle.

† As another example of the new light and interest which a knowledge of general homology gives to the facts of abnormal anatomy in the human species, I may cite the remarkable case described by Sir C. Bell (*op. cit* p. 52), of the boy 'born without arms,'—'but who had clavicles and scapulæ.' Here development was arrested at the point at which it is normal

The *centrum*, 5 *c*, of the parietal vertebra gives, in the human fœtus, the same evidence of its essential individuality, by the same absence of the mask of connation which somewhat concealed it in the oviparous classes, as we have already noticed in the lower mammal (fig. 24). The *neurapophyses* (6) rise higher to reach their proper *spine* (7) in the lofty cranial dome of man, of which that divided and enormously expanded element forms the greatest part of the roof: but the base of the neurapophysis continues to be perforated by the homologous divisions of the nerve (*tr*) that notches it in the cod-fish (fig. 5, 6 *tr*). The *parapophysis* (8) retains its autogenous or independent character in relation to its proper neural arch, the 'additamental' suture by which it manifests its normal relations to the neural spine (7) being persistent; but it speedily coalesces with the acoustic capsule, 16 (from which it is artificially separated in fig. 25), and with the modified *pleurapophysis*, 28, as has been already explained in the chapter on 'Special Homology' (Mastoid, pp. 197–210).

The proper *pleurapophysis* (38) of the parietal vertebra ordinarily becomes confluent with contiguous and coalesced portions of the parapophysis, 8, and acoustic capsule, 16; and the ossified portion of the *hæmapophysis*, 40 *h*, is separated from it by a long ligamentous tract, and becomes confluent with the *hæmal spine*, 41 *hs*. The entire inverted arch exhibits the usual arrested growth characteristic of the air-breathing vertebrates, and its appendages are represented by the still retained 'hypobranchial' elements, 46, of the splanchnic arches, which are so voluminously developed in the fish.

The *centrum* and *neurapophyses* (9, 10) of the frontal vertebra manifest the same speedy coalescence as in other mammals. The *spine*, 11, though developed from two lateral moieties, regains its normal unity, as a general rule, in man by the obliteration of the median suture: its transverse and vertical expanse here attain their maximum. The *parapophysis* (12) is developed, as in the occipital segment, as an exogenous process, called 'external angular or orbital' in anthropotomy, but from the neural spine instead of the neurapophysis. This element is perforated by its characteristic nerve (*op*). The *pleurapophysis*, 28, is now separated from its parapophysis, 12, by both parts, 27 and 26, of the diverging appendage of the maxillary arch; but yet it is interesting to note that it is still connected through the medium of these with the same element to which, agreeably with the greater retention of the vertebrate archetype, it directly articulates in the fish (fig. 5, 12, 28 *a–d*). The intercalated piece (27) further interposes itself, as in other mammals, between the pleurapophysis, 28, and hæmapophysis, 29, of the frontal segment, directly articulating with the latter and leaving the proximal element of the arch (28) reduced in man to its subordinate function of sustaining the ear-drum. The *hæmapophysis*, 29, and *hæmal spine*, 32, are connate, and soon coalesce with their

in the *Anguis*, *Pseudopus*, and some other limbless and snake-like lizards. The usual predominating development of the scapular appendage has bred so prevalent an idea of the subordinate character of the supporting arch, that the existence of the arch minus the appendage, is adverted to not without a note of surprise in the above-cited and other excellent works. General homology, however, teaches that a vertebral arch is a more constant and important part than its appendages; and, that, being anterior in the order of development, it may be expected, in cases where development is arrested, whether normally in accordance with the nature of the species or abnormally as an individual defect, to be present when the diverging appendages are absent. Sir Charles Bell, well recognising the primary function of the modified occipital rib in relation to breathing, observes, in reference to the above-cited case, "We would do well to remember this double office of the scapula and its muscles, that, whilst it is the very foundation of the bones of the upper extremity, and never wanting in any animal that has the most remote resemblance to an arm, it is the centre and point d'appui of the muscles of respiration, and acts in that capacity where there are no extremities at all!" p. 52.

opposites at the symphysis menti; and the whole distal portion of the inverted arch of the frontal segment is then formed by a continuous bar of bone, modified in its form and articulation, and by its dental appendages, in subserviency to mastication and other subordinate functions in relation to the human mouth.

We recognise the *centrum* of the nasal vertebra in the human skull by the position and connections of the bone, 13, notwithstanding it has undergone as extreme a divergence from the ordinary cylindrical shape of such elements, as its homotype at the opposite extreme of the vertebral column in birds, which Cuvier compares to a 'soc-de-charrue': it is, in fact, more compressed and vertically developed than in the hog (fig. 24, 13); but it is shorter, and commonly retains its original individuality. It directly supports the similarly modified compressed, and also, coalesced *neurapophyses*, 14, which terminating in like manner the series of their vertebral homotypes anteriorly, have undergone the extremest modification. But the arguments which show the coalesced prefrontals of the frog, the bird and the mammal to be the special homologues of the bones so called in the fish, establish, as a corollary, their general homology with those bones, which retain in so much greater a degree, and unmistakeably, their neurapophysial characters in that lowest class of cold-blooded vertebrates. The nature of the additional complication by which those vertebral or archetypal characters are further masked in mammals, has been already explained in relation to the nasal neurapophyses of the hog. The olfactory nerves are transmitted in man, as in that and most other inferior mammals, by numerous foramina, 14, *ol*. The *nasal spine*, 15, is divided, but much-restricted in its growth, and presents a singular contrast in that respect to its homotypes, 11, 7, 3, in the succeeding cranial vertebræ. The development of the neural arch of the nasal vertebra is so modified in man, so contracted as well as retracted, that the orbits, instead of being pushed apart and directed laterally, have approximated by a kind of reciprocal rotation towards the median plane, and have thus gained a directly anterior aspect.

General homology perhaps best explains the import of the continuation of the small and seemingly insignificant bones (20, *pl*) from the roof of the mouth "up the back part of the nostrils to the orbit," where they are connected "to the *ossa plana* and *cellulæ ethmoideæ* by the ethmoid suture." That the connection is the best possible for the functions of the bone we may feel assured, without the sentiment being damped by discerning in it, at the same time, the attempt to retain the type, and repeat those constant connections of the *pleurapophysis* in question, not only with its centrum (vomer), but also with the modified neurapophyses of its proper segment (prefrontals with coalesced olfactory capsules constituting the compound 'ethmoid bone' of anthropotomy). The connections of the pleurapophysis, 20, with its hæmapophysis, 21, in front, and its diverging appendage, 24, behind, are also retained in man; and in short, all those characters that, depending on the essential nature of the palatine bone as the pleurapophysis of its vertebral segment, have served to indicate its special homology from man to the fish, without doubt or difficulty, to all anatomists (see Table I.).

The *hæmapophysis* (20) has the usual mammalian expansion, but is unusually short in man, and coalesces unusually early with the corresponding moiety of the *hæmal spine* (22). Besides the normal and constant connections with 20 and 22, the hæmapophysis, 21, articulates with its fellow, with the centrum (13), neurapophysis (14, os planum), and spine (15), of its own vertebra, with the spine of the frontal vertebra (11), with the detached portion of the olfactory capsule (19), and with the muco-dermal bone (73). It also affords a large surface of attachment to the proximal piece of

its diverging appendage (26), which, in addition to the more constant connections with 21 and 27, articulates in man with the neurapophysis (10) and parapophysis (12) of the frontal vertebra. The distal extremity of the second bone (27) of the diverging appendage attains its maximum of expansion in man, and besides its connection with 26, and the glenoid articulation for the hæmapophysis, 29, it joins the parietal neurapophysis, 6, and spine, 7, and sometimes also (in the melanian race) the spine (11) of the frontal vertebra: and it speedily coalesces with the reduced pleurapophysis, 28, of the frontal vertebra, and with the parapophysis (8) of the parietal vertebra, together with a portion of the capsule of the acoustic organ.

In reviewing the general characters of the human skull in reference to the vertebrate archetype, we find the occipital segment simplified by the atrophy and connation of its parapophyses and hæmapophyses; and modified chiefly by the excessive growth of its neural spine and pleurapophyses, and by the backward displacement of the latter element, as in all other air-breathing vertebrates. The parietal segment, retaining, like the occipital one, the more normal proportions of its centrum and neurapophyses, is still more remarkable for the vast expanse of its permanently bifid spine. As in most cold-blooded vertebrates, the parapophysis preserves its independence in respect of the neural arch of its own segment. The hæmal arch retains its almost fœtal proportions, but is less displaced than in some of the inferior air-breathing vertebrates. The primitive individuality of the centrum of the parietal vertebra is a feature by which the human subject, together with all other mammals, manifests a closer adhesion to type than is observable in this part of the skull in any of the oviparous vertebrates, and it shows the necessity of extending comparisons over the entire series, and not deducing the vertebrate archetype exclusively from those inferior forms: for although it may be upon the whole best retained in them, yet the modifications superinduced in subserviency to their exigences, and by which they diverge to that extent from the common plan, and, as a series of species, from the common vertebrate stem, may affect a part which the conditions of existence of higher forms do not require to be so masked. The early ossification and large proportional size of the hyoidean arch in the human embryo is very significant of its true nature and importance, in relation to the archetypal vertebrate structure, *i. e.* as being the hæmal complement of a primary segment of the skull.

Exogenous processes descend, like the pair from beneath the lower cervical vertebræ of some birds, from the body of the parietal vertebra; but the true transverse processes are the mastoids, which always articulate with a corner of the parietals.

The centrum and neurapophyses of the frontal segment retain their ordinary proportions, and the spine is again the element which, by its extreme expansion and its modification in subserviency to the formation of the orbits, chiefly masks the typical features of the neural arch. The parapophysis is connate and reduced in size, and its vertebral relations with the pleurapophysis of its segment interrupted by the interposition of the diverging appendage from the antecedent hæmal arch: the unusually expanded distal end of the same appendage also intervenes between the frontal pleur- and hæmapophyses; the pleurapophysis (28) being more atrophied in man than in most inferior mammals. The hæmapophysis and spine are on the other hand much developed and modified as above described, for the business of mastication, though relatively shorter than in other mammals.

The compression and extension, both vertically and longitudinally, of the centrum (13), the compression and coalescence of the neurapophyses (14), both with each other and the nasal capsules (18), and the corresponding proportions

of the divided spine (18), mainly characterize the neural arch (N IV) of the terminal or nasal segment of the human skull. The early coalescence of each hæmapophysis(21) with the corresponding half of the divided hæmal spine (22), and the unusual expansion of the bones, especially the second (27), which diverge from the hæmapophysis, form the chief characteristics of the hæmal arch (H IV) of the nasal segment. The hæmapophysial portions of both the nasal and frontal vertebræ are much less elongated than in most other animals.

It may serve to test the accuracy of the general homologies here assigned to the bones of the human skull, if we notice the degree to which they have been subject to modification in connection with such determinations.

According to the general character of the vertebral elements in the rest of the frame, we should be prepared to expect that the hæmal arches would be subject to a greater variety in respect of development and relative position to their segments than the neural arches; and that in the latter the parts determined as centrums and neurapophyses would retain more of the ordinary proportions of such parts in other segments or in other animals, than the peripherally situated spines. If new bones are added, we should expect to find them in the relative position of appendages to the normal vertebral arches: or should these be homologous with similar superadditions in the skulls of lower animals, they will probably be the seat of more extensive changes of form, proportion and connections, than the elements of the vertebral arches themselves.

Now if the reader will glance at fig. 25 and compare the bones forming the segments of the skull with those in figs. 24, 23, 22 and 5, he cannot but be struck with the remarkable degree of uniformity in the dimensions of the bones 2, 6 and 10: no. 14 being the terminal neurapophysis, has been the seat of more variety; but the general steadiness of this series of bones in regard to their dimensions and connections accords with the characters assigned to them, as neurapophyses, which are always the most constant and important of the ossified vertebral elements.

The bones 1, 5, 9 and 13 equally conform in the kind and degree of their modifications with their determination as the bodies of the vertebræ.

The increasing capacity of the neural canal of the head, demanded for the lodgment of the progressively expanded encephalon as the vertebral scale rises, is chiefly acquired by the expansion of the bones, 3, 7, 11, which, being determined as 'neural spines' in the fish, might be expected to be subject to greater deviations from their typical form and proportions than the more central and essential parts of the neural arches. The terminal neural spine, 15, is subject to still greater varieties in the range of species, as might also be expected from its position. In one mammal, *e. g.* the porcupine, it is more expanded than any of its succeeding homotypes in the cranium; in man its proportions are so much reduced as greatly to mask the homotypal relation. In one mammal, *e. g.* the orang, the nasal spine is not only diminutive but single: in another mammal, *e. g.* the manatee, it is also diminutive but divided, and the halves completely separated by the intervention of part of the succeeding spine.

The abnormal conditions of the human skull give further illustration of the truth of these general homologies of the cranial bones, and reciprocally receive light from such determinations. In the case of idiots from defective growth or development of the brain, where the cavity of the cranium is reduced to half or less than half its normal capacity, as *e. g.* in the skull described and figured in my 'Memoir on the Osteology of the Chimpanzee*,' it might

* Zoological Transactions, vol. i. p. 343, pl. 57 and 58.

have been expected from the anthropotomical ideas of the cranial bones,—according to which no one bone is deemed either more or less important than another in its essential nature, and where the squamosal is as little regarded in the light of a superadded or intercalary piece as the alisphenoid,—that all would be reduced in the same proportion in forming the parietes of the contracted brain-chamber. But this is by no means the case. In the instance above-cited the basioccipital and basisphenoid have been developed to their usual size, and the distance from the posterior boundary of the bony palate to the anterior border of the foramen magnum is as great as in any normal skull. The exoccipitals (condyloid portions of the occiput), the alisphenoids and the orbitosphenoids retain in like manner their full dimensions. The distance between the frontal and temporal bones is as great as in the average of fully developed Caucasian skulls, and is greater than in most of those from the Melanian race, in which the direct junction of the frontal with the temporal, as in the chimpanzee, is by no means rare. The contraction of the capacity of the brain-chamber is due chiefly to arrested development of the frontals, parietals, supraoccipital and squamosals. By the reduction of the supraoccipital and the retention of the centrums of the cranial vertebræ of their normal proportions, the foramen magnum becomes situated nearer the back part of the basis cranii than in the normal skull.

In a still smaller craniun of a female idiot, who reached the age of twenty-one years, which is preserved with the male idiot's skull above-mentioned in the anatomical museum of St. Bartholomew's Hospital, the contrast between the normal proportions of the basioccipital, basisphenoid, exoccipitals, alisphenoids and orbitosphenoids, on the one hand, and the reduced dimensions of the supraoccipital, parietals, frontals and squamosals on the other, is still more striking and significant of the true nature of those bones. The normal growth of the centrums, indeed, might be explained by the concomitant nearly normal size of the medulla oblongata, base of third ventricle and optic chiasma, in the brain of the same idiot: but it is not so obvious from the condition of the brain itself why the alisphenoid should not have shrunk in the same proportion as the parietals, frontals and squamosals. To the homologist, however, the recognised difference of subjectivity to modification presented by the neurapophyses, spines and diverging appendages of the typical segments, renders very intelligible the partial seats of arrested growth in the bones of these idiots' crania.

In reference to disease, also, one sees not why the alisphenoid should have a minor attraction for the morbid products deposited, or be less subject to the destructive actions excited, during syphilitic or mercurial disease, than the parietals, or the orbitosphenoids than the frontals, or the exoccipitals than the supraoccipital: yet it needs but to examine any series of such morbid skulls in our museums of pathology to be convinced that the variable and peripheral elements of the neural arches, viz. their expanded spines, are almost exclusively so affected: the frontal and parietal being the most common seats of the disease; the supraoccipital a less frequent one, concomitantly with its minor deviation from the typical standard of the element. I have yet seen no example in which either a cranio-vertebral centrum or neurapophysis was so affected; but the nasal bones are notoriously attacked.

It would be easy to multiply such instances of the new light—new eyes, so to speak,—with which human anatomy, normal and abnormal, is viewed, after the essential nature or general homology of the parts have been appreciated.

If the bones 4, 8, 12, fig. 5, have been correctly determined as the parapophyses of the cranial vertebræ, they might be expected to be subject in the

course of adaptive modification to the loss of their individuality, and from autogenous elements to be reduced to the condition of exogenous processes. Now this is exactly what we trace in the series of vertebrate skulls; and we are further prepared to expect that the simplification of the segment forming the anterior extremity of the vertebral series will be in part effected by the total disappearance of its least important elements, the parapophyses. These are, in fact, absent in the nasal vertebra in all animals; they become confluent with the occipital vertebra in most reptiles and all warm-blooded animals; and in the latter, we find, with the exception of a few birds, that the parapophyses of the frontal vertebræ have likewise lost their individuality.

The first endoskeletal bones which plainly disappear from the skull in tracing its modifications upwards from fishes are those which, in the present vertebral theory, have been referred to the category of diverging appendages; viz. the entopterygoid (fig. 5, 23), the opercular (*ib.* 34–37), and the branchiostegals (*ib.* 44). The first bones that we discover to be plainly superadded to those that remain after the above subtraction, in the skull of the reptiles, for example, are, also, referable, in the present vertebral theory, to the same variable and inconstant class of elements: they are the ectopterygoids (fig. 22, 24′), the malars (figs. 22 to 25, 26) and the squamosals (*ib.* 27); and are, in general homology, diverging appendages of the palato-maxillary arch. They are subject to more inconstancy as to their existence than the more regular and normal elements of the skull: some reptiles, for example, have the malar and squamosal, whilst others want them; most reptiles have the ectopterygoid, but this, which is not present in fishes, is again taken away in the warm-blooded vertebrates. With reference to inconstancy of form and connections no bone of the cranium exceeds the squamosal, and it is precisely this distal element of the diverging appendage, which, through its inordinate development, most masks the archetypal character of the human cranium (compare 27, fig. 25, with 27, fig. 23).

Classification of Skull-bones.—A knowledge of the special homologies of the bones of the skull is essential to that of their general homology, and a knowledge of their general homology is indispensable to their natural classification.

Cuvier divides the bones of the head in all animals into bones of the *cranium* and bones of the *face*.

The bones of the cranium are those of the cavity containing the brain: all the rest are bones of the face and contribute to form the cavities for the organs of sight, smell and taste*. But these primary divisions do not include the same bones in all animals: the nasal (fig. 5, 15) and vomer (*ib.* 13) are cranial bones in fishes, but not in mammals: the squamosal (fig. 25, 27) is a cranial bone in mammals and not in birds or reptiles, &c. And this discrepancy in the Cuvierian classification of cranial bones is due, not only to a non-appreciation of their essential nature, but partly to mistakes of special homologies: thus the nasal is called ethmoid in the fish, and the squamosal is called jugal in the bird.

In all anthropotomical classifications the bones of the *cranium* are reckoned eight in number: four single, viz.—

The frontal (fig. 25, 11);
The ethmoidal (*ib.* 14 and 18);
The sphenoidal (5, 6, 9, 10 and 24);
The occipital (1, 2 and 3): and
four in pairs, viz.—
The two parietal (7), and
The two temporal (8, 16, 27, 28 and 38).

* Leçons d'Anat. Comp. t. ii. (1837) p. 159.

The bones of the *face* are reckoned as fourteen in number, viz.—
The two malar (26);
The two maxillary (21, 22);
The two palatal (20);
The two nasal (15);
The two turbinal (19);
The vomer (13), and
The mandible (29–38).

The detached portion of the hyoid arch (40, 41) and its appendages (47), together with the whole of the scapular arch and its appendages, are excluded from the category of the bones of the head.

The natural classification of the bones of the human skull appears to me to be, first into those of
The ENDO-SKELETON,
The SPLANCHNO-SKELETON, and
The EXO-SKELETON.

The primary division of the bones of the *endo-skeleton* is into the four segments, called
Occipital vertebra, N I, H I;
Parietal vertebra, N II, H II;
Frontal vertebra, N III, H III;
Nasal vertebra, N IV, H IV.

These are subdivided into the neural arches, called
Epencephalic arch (1, 2, 3);
Mesencephalic arch (5, 9, 7, 8);
Prosencephalic arch (9, 10, 11 and 12);
Rhinencephalic arch (13, 14, 15):
and into the hæmal arches and their appendages, called
Maxillary arch (20, 21 and 22) and appendages (24, 25, 27);
Mandibular arch (28, 29–32) (no appendage);
Hyoidean arch (38, 40, 41) and appendages (46);
Scapular arch (51 and 52) and appendages (53–58).

The bones of the *splanchno-skeleton*, are
The petrosal (16) and otosteals (16′)*;
The turbinals (18 and 19) and teeth. (The sclerotals retain their primitive histological condition as fibrous membrane.)

The bones of the *exo-skeleton*, are
The lacrymals (73).

* These ossicles are described by most anthropotomists as parts of the 'temporal bone.' "Os temporum infantis magnopere ab osse temporum adulti differt; labyrinthi et ossiculorum auditûs fabrica absoluta est," says Soemmerring in the classical work before cited (t. i. p. 132). The signification of the differences between the fœtal and adult human temporal bone, which the great anthropotomist truly regarded as so remarkable, is made plain by anatomy; which shows the bone to be an assemblage of several essentially distinct ones, and at the same time exposes the character of that singularly heterogeneous assemblage and coalescence of osseous elements to meet the exigences of the peculiarly developed frame of man. What the 'ossicula auditûs' are, is a problem which still awaits careful additional research in the embryonic development of the hæmal arches of the cranium, for its satisfactory solution. The question is not, of course, whether they are dismemberments of the 'temporal bone,' since this has no real claim in any animal to an individual character; but whether the ossicles of the ear-drum in mammals are to be regarded, like the pedicle of the eye-ball in the plagiostomous fishes, as appendages to a sense-organ, and thereby as developments of the splanchno-skeleton; or whether they are, like the tympanic ring, modifications of the tympano-mandibular arch. The reasons are adduced in the Chapter on 'Special Homology' (p. 235) which have led me to view them as peculiar mammalian productions in relation to the exalted functions of a special organ of sense.

The course of coalescence reduces the epencephalic arch (fig. 25, N 1) to one bone, the scapular arch to one bone (the arch is apparently completed by the connexion of an element (22′) not appertaining to the skull). The centrums 5, (9) and neurapophyses (6, 10) of the parietal and frontal vertebræ coalesce together and with the diverging appendages (24) of the maxillary arch to form one bone, the 'sphenoid' of anthropotomy, and this ultimately coalesces with the epencephalic arch and constitutes the 'os spheno-occipitale' of Soemmerring. The expanded halves of the parietal spine (7) remaining usually distinct are reckoned as two bones. The expanded halves of the frontal spine (11) usually coalescing together form a single bone. The halves of the nasal spine (13) rarely coalescing are counted as two bones. The mastoid (8) coalescing with the petrosal (16) and this with the tympanic (28), squamosal (27) and stylohyal (30), the whole is reckoned a single bone, which thus combines a parapophysis and pleurapophysis of one vertebra with a pleurapophysis of another and a diverging appendage of a third vertebra, and all these parts of the endo-skeleton become confluent with a sense-capsule belonging to the splanchno-skeleton: such is the heterogeneous compound character of the 'temporal bone' of anthropotomy. The neurapophyses of the nasal vertebra (14) coalesce with each other and with a considerable part of another ossified sense-capsule (18), to form the single bone called 'ethmoid.' The maxillary bone includes the superior maxillary (21) and premaxillary (22) of the lower animals. The hyoid bone includes the basihyal (41), with the ceratohyals (40) and the thyrohyals (46). The scapula includes both the pleurapophysis (51) and the hæmapophysis (52) of the occipito-hæmal arch. The signification of the separate points of ossification of the human fœtal skull is made plain by the foregoing applications of the ascertained general homologies of the bones of that part of the skeleton.

Objections to the Cranial vertebræ considered.—The latest and most formal objection to the fundamental idea on which the general homologies of the bones of the head have been worked out in the present Report, is also the most formidable in respect of the great and deserved eminence of the objector. In a manuscript left by Baron Cuvier, entitled, "Le crâne est-il une vertèbre ou un composé de trois ou quatre vertèbres?" appended to the posthumous edition of the 'Leçons d'Anatomie Comparée*,' he admits that "the analogy of the basilar and two condyloid parts of the occiput with the body and two halves of the annular part of the atlas is very appreciable. The basioccipital and the body of the atlas serve equally to support the myelon; the exoccipitals and the two halves of the ring of the atlas to cover it. The condyles are represented by the articular processes by which the atlas is joined to the dentata. The condyloid foramen, which gives passage to the nerve of the ninth pair, has some relation with the hole in the atlas which gives passage to the first cervical nerve and to the first bend of the vertebral artery. Some have also found a certain relation between the mastoid process, which in most animals appertains to the occipital bone, and the transverse process of the atlas and the other vertebræ; upon which it must be remarked that these relations are less in man, in some respects, than in the quadrupeds, since the atlas has commonly only a notch for the passage of the artery, and the mastoid belongs in man entirely to the petrosal"†. "We may even com-

* Tome ii. p. 710. (1837) par MM. F. G. Cuvier and Laurillard, who hold the arguments of their author to be conclusive. The criticism in the 'Histoire des Poissons,' t. i. p. 230, bears only upon the *à priori* cranio-vertebral theory of Geoffroy, and does not concern us here.

† "L'analogie de ces trois pièces, le basilaire et les deux condyloïdiens, avec les trois pièces de l'atlas, son corps et les deux moitiés de sa partie annulaire est très sensible. Le basilaire et le corps de l'atlas servent également à supporter la moëlle épinière; les condy-

pare," Cuvier says, "the supraoccipital to the spinous processes which in certain animals originate by special points of ossification and remain for some time distinct from the rest of the vertebra: nevertheless, there is already here a great difference of structure and function*." With regard to the points in which Cuvier is willing to admit an 'analogy' between the occiput and the atlas, he subjoins, agreeably with his idea of the law which governed such correspondences,—"These resemblances might naturally be expected in the part of the head placed at the extremity of the vertebral column, and the functions of which are, in fact, analogous to those of vertebræ, since it gives passage, like them, to the great neural axis†."

With regard to the feature of resemblance (quelque rapport) which some had seen between the mastoid process and a transverse process, Cuvier founds his objection to its application to the vertebral character of the occipital bone on a false homology. Concluding that the mastoid in man (fig. 25, s) was homologous with the paroccipital in the hog (fig. 22, 4)‡ and some other quadrupeds, he deems the determination of the paroccipital as the transverse process of the occipital vertebra to be invalidated by the fact that the 'mastoid' belongs, in man, not to the occipital but to the petrosal. There were cases, however, not unknown to the able Editors of the posthumous edition of the 'Leçons d'Anatomie Comparée,' where the true transverse processes of the occipital vertebra, though exogenous, like those of the succeeding trunk-vertebræ in man, had become developed to an equal extent with such transverse processes; the abnormality of the human occipital thus repeating its normal condition in the quadruped. They however do not cite these instances, or notice the confusion by their author of the true mastoid with the paroccipital in reference to this his first objection to the vertebral homology of the occipital segment. But it might further have been remarked, in respect of the segment of the skull to which the mastoid really stands in parapophysial relation, that although the mastoid belongs in man to the petrosal in the sense of being anchylosed with it, it articulates with the parietal; and the persistence or obliteration of a primitive suture is too variable a phænomenon to determine to which of two bones a third connected with both essentially belongs. The constant existence of the paroccipital either as an autogenous element or an exogenous transverse process in all the oviparous vertebrate classes, its common existence in mammals, and occasional, though rare, development in man, establish that additional, though by no means essential vertebral character in the occipital segment, which

loïdiens et les deux moitiés de l'anneau de l'atlas à la couvrir. Les condyles sont représentés par les facettes articulaires au moyen desquelles l'atlas s'unit à l'axis. Le trou condylien qui laisse passer le nerf de la neuvième pair, a quelque rapport avec le trou de l'atlas qui laisse passer le premier nerf cervical, et la première courbure de l'artère vertébrale. On a aussi trouvé quelque rapport entre l'apophyse mastoïde qui, dans la plupart des animaux, appartient à l'occipital, et l'apophyse transverse de l'atlas et des autres vertèbres; sur quoi il faut remarquer que ces rapports sont moindres dans l'homme à certains égards que dans les quadrupèdes, puisque l'atlas n'y a ordinairement qu'une échancrure pour le passage de l'artère et que l'apophyse mastoïde y appartient entièrement au rocher."—*l. c.* p. 710.

* "On pourrait même comparer l'occipital supérieur aux apophyses épineuses qui, dans certains animaux, naissent par des points d'ossification particuliers, et restent quelque temps distincts du reste de la vertèbre; cependant il y aurait déjà ici une grande différence de structure et de fonction."—*l. c.* p. 711.

† "Ces resemblances étaient naturelles à attendre dans la partie de la tête placée à l'extrémité de la colonne vertébrale, et dont les fonctions sont en effet analogues à celles des vertèbres puisqu'elle laisse passer comme elles le grand tronc medullaire."—*l. c.* p. 711.

‡ Cuvier, *e. g.* describes this element as "L'apophyse mastoïde, qui est très-longue, très-pointue et toute de l'occipital," in his elaborate *Ossemens des Cochons*, Oss. Fossiles, t. ii. pt. i. p. 117.

Cuvier seeks to obscure by the normal absence of its proper transverse processes in man, and the assumed transference of them to another part of the skull.

Cuvier in the next place objects to the comparison of the supraoccipital with the neural spine of a trunk-vertebra, "because of its vast difference of structure and function." He does not specify the nature of the difference: he admits that the neural spines have distinct centres of ossification in certain animals; and all will allow that, in most of the trunk-vertebræ of such, the neural canal is closed by the coadapted ends of the neurapophyses to which the spine articulates or becomes anchylosed: that therefore such spine does not directly cover the neural axis, but, retaining the shape signified by its name, performs exclusively the function in relation to muscular attachments. At first view the contrast seems conclusive against all homology between such mere intermuscular spine and the broad thin convex plate applied over the cerebellum and posterior cerebral lobes in man. And it must be confessed that the determination of their general homological relations could not have been satisfactorily demonstrated by the mere relations of the parts to the laminæ supporting them, in so limited a range of comparison. But, if we descend to the fish, we shall find the supraoccipital equally excluded from the neural canal by the meeting of the exoccipitals beneath its base; we shall, also, see it still retaining the spinous figure, indicating its function in relation to muscular attachments to predominate over that in subserviency to the protection of the epencephalon. If we next ascend to the crocodile, we shall find the neural spine of the atlas to be one of those examples alluded to by Cuvier, where the ossification proceeds from an independent centre: and it not only thus manifests its essential character as an autogenous vertebral element, but maintains its permanent separation from the neurapophyses: and it further indicates the modifications of form to which the corresponding elements will be subject in the more expanded neural arches of the antecedent cranial segments by having already exchanged its compressed spinous for a depressed lamellar form. Here indeed Cuvier might not only have objected to recognise it as a vertebral spine by reason of its change of form and function, but also by its continuing a distinct bone, which is not the case with the expanded 'spine' of the mammalian occipital vertebra. But returning to the crocodile, we observe in the segment anterior to the atlas that both the form and connections of the supraoccipital (fig. 22, s) are so closely similar to those of the neural spine of the atlas that the recognition of their serial homology is unavoidable; and we have a repetition of the same characters of the vertebral element in question in the small and undivided parietal (*ib.* 7). Now Cuvier makes no difficulty in admitting the 'occipital supérieur' in the crocodile to be the homologous bone with its more expanded namesake in the bird; or this with the still more expanded 'partie grande et mince de l'occipital' in mammals and man: he is also disposed to admit the special homology of the supraoccipital under all its variations of form and function in the above-cited air-breathing animals with the bone s in fishes, which he sometimes calls 'occipital supérieur,' sometimes 'interpariétal.' If then the special homology be admitted on the ground of the constancy of the connections of the part, with what show of reason can its general homology be rejected which forms the very basis or condition of the characters determinative of such admitted special homology? But Cuvier is not consistent with himself in his grounds of objection to the essential nature of the human supraoccipital as the neural spine of its segment; for he does not hesitate to call the atlas of the crocodile a vertebra,

although its 'annular part' is closed above by a transverse plate* instead of by a vertical spine, of which, indeed, there remains hardly more vestige than is presented by the tubercle or rudiment of the spinous process in the supra-occipital of man. It must also be remembered, that the human supraoccipital does retain to a certain extent the same function in relation to the attachment of the proper vertebral muscles (*splenii capitis, complexi*, and the modified interspinales called '*recti capitis postici maj. et min.*) as the succeeding vertebral spines; and combines this with the same place of completing, as the key-stone, the neural arch; although by reason of the more voluminously developed segment of the neural axis protected by that arch the peripheral element is chiefly modified for the acquisition of the required increase of space.

Cuvier next proceeds to comment on Oken's endeavour to represent the basisphenoid and the two alisphenoids with the two parietals as forming a vertebra: and he admits that there is some analogy, though this is much more feeble than the differences. "The basisphenoid, having another function, takes on a different form from the basioccipital, especially above, by virtue of the posterior clinoid processes: and in the embryo it is composed not of a single nucleus, but of two†." With respect to the objection from the modification of form alluded to, it may be remarked that the same element in other vertebral segments of the body undergoes much greater change of shape; the centrums of the lower cervical vertebræ in many birds send down two processes as well-marked as the ascending ones called 'clinoid' in that of the parietal vertebra, not to speak of the 'soc de charrue' of the coccygeal vertebræ of the bird, for example, without any difficulty having been felt or expressed by Cuvier in their recognition as modified vertebral bodies, the more essential characters of their general homology being as plainly retained as in the case of the basisphenoid; in its relation, *e. g.* to the neurapophyses and the support of the mesencephalon. With regard to the objection from the two centres of development, if this be valid against the general homology of the basisphenoid (*a*, fig. 25) as a vertebral centrum, it equally tells against the body of the atlas (*c*), which, as Cuvier well knew, was ossified sometimes from two, and sometimes from three centres‡. And I may further observe that, although Cuvier affirms the two ossific centres of the basisphenoid to retain for a long time between them simple cartilages, my observations bear out the accuracy of the remark of Kerkringius, (whose figures Cuvier cites,) touching the "dua ossicula distincta" (tab. xxxiv. fig. iii. *c*, *c*), viz. "quæ celerrimè in formam figuræ appositæ K coalescunt": and the figure of the coalesced rudiments of the basisphenoid given by Kerkringius closely resembles the bilobed rudiment of the vertebral centrums in the sacrum of the chick.

Cuvier next objects to the neurapophysial character of the alisphenoids, that the 'foramen ovale' is rarely a notch, more often a complete hole.

* "*Les vertèbres.* L'atlas est composé de six pièces, &c.—La première, *a*, est une lame transverse qui fait le dos de la partie annulaire. Elle n'a qu'une crête à peine sensible pour toute apophyse épineuse."—Ossemens Fossiles, t. v. pt. ii. p. 95.

† En avant du basilaire se trouve le corps du sphénoïde postérieur, aux côtés duquel adhèrent les deux ailes temporales ou grandes ailes. On a aussi cherché à représenter ces trois pièces comme formant une vertèbre avec les deux pariétaux. Il reste en effet encore quelque analogie, mais beaucoup plus faible, tandis que les différences deviennent plus fortes. Le corps du sphénoïde a bien l'air d'une répétition du basilaire, mais ayant une autre fonction il prende aussi une autre forme, surtout en dessus, au moyen des apophyses clinoïdes postérieures; et dans les premiers temps du fœtus il n'est pas composé d'un seul noyau, mais de deux, qui ont long-temps entre eux de simples cartilages."—*l. c.* p. 712.

‡ Leçons d'Anat. Comparée, t. i. (1836) p. 174. Meckel has figured the variety of three ossific centres in this element of the human atlas in the 1st vol. of his Archiv für die Physiologie, taf. vi. fig. 1.

"Now," he urges, "vertebræ properly so called give passage to the nerves only by the intervals that exist between them and the other vertebræ, and not by particular foramina*." Therefore the young anatomist must conclude that the dorsal vertebræ of the ox, the abdominal vertebræ of the lophius, and every other segment of the trunk whose neural arches are directly perforated by the spinal nerves, are to be rejected from the vertebral category!

It has been shown in the generalities on the corporal vertebræ (p. 265), that the neurapophyses in relation to the passage of their governing nerves may be either untouched, notched or perforated by them, without prejudice to their neurapophysial character. Viewed in the entire series of vertebrata the cranial neurapophyses are more frequently perforated than notched, those of the trunk more frequently untouched or notched by the nerves in passing through their interspaces.

The penetration and sagacity of Cuvier nowhere shine forth more brightly than in his bold and true determination of the bone *s*, fig. 5, in the cod-fish† as the homologue of the temporal wing of the sphenoid in the human skull. To any less-gifted comparative anatomist the relation would have been masked by the coalescence of the homologous part in man, by its connections with the squamosal and frontal, and its comparatively small proportions under the guise of a subordinate process; none of which characters exist in the alisphenoid of fishes: it still retains, however, in that class, as in man, its most essential connections in relation to the bones of its own segment and to the brain and nerves; and Cuvier availing himself of these in the determination of its special homology, was little likely to be swayed by so unimportant a variety as the transmission of the characteristic nerve by a foramen instead of by a notch. No sooner, however, has the time arrived and the call been sounded for an advance to a higher generalization, which includes and explains the minor proposition, than Cuvier interposes the least important difference of the alisphenoid to check the progress. It will be obvious to the anatomist that the foregoing explanation of the value of the nerve-notch or hole in the homological character of a neurapophysis has been called forth by the weight of the name of the objector rather than by the force of the objection.

Cuvier directs his next argument against the vertebral character of the (neural arch of the) parietal segment generally. "Its composition," he avers, "is different from that of other vertebræ, since the ring (he had just before denied its annular form) would be composed of five pieces or even of six, including the interparietal." Yet Cuvier does not hesitate, in his Article V., '*Les Vertèbres*' (Ostéologie des Crocodiles)‡, to reckon as the first vertebra, the atlas notwithstanding its composition of six pieces.

If, indeed, Cuvier had subscribed to Geoffroy's assertion, that "Nature reproduces the same number of elements, in the same relations, in each vertebra, only she varies indefinitely their form,"—his objection to the vertebral character of any given segment that might deviate from the assumed normal number of pieces would have been intelligible. But even, then, he would not have been guided consistently by his own principle; for the objection founded upon the supposed abnormal number of pieces in a cranial segment weighs

* "Ses ailes diffèrent beaucoup plus encore et des deux condyliens, et des deux pièces qui forment la partie annulaire des vertèbres. A la vérité, le trou ovale n'est quelquefois qu'une échancrure; mais le plus souvent il est entouré d'os, et par conséquent un vrai trou. Il en est de même du trou rond toutes les fois qu'il est distinct du sphéno-orbitaire; or les vertèbres proprement dites ne laissent passer les nerfs que par les intervalles qui existent entre elles et les autres vertèbres, et non par des trous particuliers."—*l. c.* p. 712.

† Règne Animal, 1817. pl. viii. fig. 2, *o*, p. 184.

‡ "L'atlas est composé de six pièces qui, à ce qu'il paroît, demeurent pendent toute la vie distinctes."—Ossemens Fossiles, t. v. pt. ii. p. 95.

not at all against the recognition of a corresponding segment of the trunk, though similarly composed.

In fact, throughout this attack upon the vertebral theory of the skull, it will be seen that it is based upon the *à priori* assumption that all the endoskeletal segments of the trunk, however modified, are vertebræ, and all those situated in the head, are not vertebræ. The essential character of a vertebra is thus deduced from its position, not its composition. It needs only to compare any of Cuvier's objections to the vertebral character of the cranial segments, with the modifications of the corporal segments admitted by him to be vertebræ, previously enumerated in this Report (pp. 264–270), to see that the characters of the cranial vertebræ objected to by Cuvier differ in degree not in kind, and become valid arguments against the admittance of natural segments into the vertebral category, only when they happen to be situated at or near the commencement of the series.

It has been abundantly proved, I trust, that the idea of a natural segment (vertebra) of the endoskeleton, does not necessarily involve the presence of a particular number of pieces, or even a determinate and unchangeable arrangement of them. The great object of my present labour has been to deduce, by careful and sufficient observation of Nature, the relative value and constancy of the different vertebral elements, and to trace the kind and extent of their variations within the limits of a plain and obvious maintenance of a typical character.

In reference to the neural arch, the variation in the number and disposition of its parts, illustrated in the figures 1, 2, 3, 4, 18, 19, 20, 21, do not seem to me, nor will they I apprehend to any unbiassed anatomist, to obliterate the common typical character of that part of a vertebra. Those elements which are furthest from the centrum are the chief seat of the changes. If the reader will compare figure 2 with figure 19, he will see for example that the crown of the arch is formed by a single bone (*r*) in the crocodile, but by two bones (*r*, *r*) in fish; nay, in most fishes the halves are even pushed apart by the interposition of a third bone. Yet the sagacity of Cuvier led him to determine the divaricated moieties of the divided parietal in such fishes to be the same (homologous) bone with the single parietal of the crocodile. With what consistency, then, can the general homology of the segments be rejected, which suffer no other change in their composition than that resulting from the single or bifid character of the same bone in each? Is the single frontal of the human adult regarded as a distinct bone from the bifid frontal of the fœtus? If, therefore, the neural arch of the parietal vertebra (mesencephalic arch) of the crocodile be free from the objection, raised by Cuvier to the vertebral character of the homologous arch in man, on the score of the number of its elements; neither can that objection be allowed to have any force when it rests upon the mere division in the human mesencephalic arch of the recognised homologue of the single spinous element in the crocodile.

In the sheep, the arch which encompasses the epencephalon is formed by only three elements, the neural spine resting upon the conjoined upper ends of the neurapophyses. In the dog these elements are divaricated and the epencephalic arch is closed above by the neural spine. Now Cuvier does not allow this difference of arrangement of the latter element (*s*) to affect his recognition of the 'suroccipital' in both mammals; and, therefore, one is at a loss to discover the consistency of the ideas which would repudiate the general homology of the bones or of the entire arches which they surmount, because, as Cuvier would say, "the composition of the arch is different, being of three pieces in the sheep and of four pieces in the dog." Yet this is precisely the kind of objection which he has directed against the mesencephalic arch, viz. because it may be composed of five or even six pieces, in certain

animals. In the fish, in fact,—by reason of the parietal parapophyses (s, s) being subject to the same variation in their relative position to the other elements, which has been illustrated in respect of the neural spine in the epencephalic arch of the dog and sheep,—the mesencephalic arch is composed of seven pieces, or, including the interposed supraoccipital, of not less than eight bones. Yet even here we clearly and easily trace the kind and degree of modification to which the fundamental plan of the neural arch has been subject. The archetype is nowise obliterated: the general homologies of the modified elements are not less recognisable than their special homologies. The centrum and neurapophyses are the steadiest elements: the spine is not only subject to great diversity of size and shape, but to some variety of position, and, moreover, to be either single or bifid: the parapophyses have less range of variety in point of dimensions, but may be more or less interposed between spine and neurapophyses, or may become confluent with either element. Thus the epencephalic arch of the crocodile (fig. 18) differs essentially, in a Cuvierian sense, from that of the tortoise or the fish (fig. 1), because it is composed of four pieces in the first and of six pieces in the latter; the difference of composition merely depending, however, on the more exterior position and connation of the parapophyses, *s*, *s*, in the crocodile.

The independency of the parietal and frontal bones is next urged by Cuvier as militating against the idea that they complete a vertebral arch formed respectively by the alisphenoids and orbitosphenoids as the piers or haunches: and the more so, inasmuch as they are separated from those bones in some animals by the intercalation of the squamosals[*]. By parity of reason we must reject the general homology of the neural arch and spine of the atlas in the *Ephippus* and some other fishes, because that part of the vertebra is not only distinct, but uplifted and removed from the piers or base of the arch by the intercalation of the articular processes of the neural arches of the occiput and axis. According to Cuvier such separated atlantal arch must be regarded as a new bone, and the centrum ought therefore equally to be viewed as 'une pièce particulière qui a une destination particulière': but the general homology of vertebral elements may be determined not only by their relations to their own segment, but by those which they maintain with their less modified homotypes in contiguous segments.

The centrum of the atlas in the *Ephippus* directly sustains other neurapophyses than its own, and so far has a new or particular function; but, since it continues to unite the centrum of the axis with that of the occiput, we still regard it as their homotype, and as standing in the relation of the centrum to its uplifted and shifted neurapophyses. So, likewise, although these elements now aid in strengthening the joint between the zygapophyses of the neural arches of the occiput and axis, and thus perform a new and very peculiar function, their relation to these and other neural arches in the series of vertebræ renders it impossible to overlook the serial homology of the separated 'laminæ' of the atlas and that of its spine with the other and larger vertebral laminæ and spines.

* "Dans tous les cas, on ne pourrait regarder cette vertèbre comme annulaire, ni supposer que les pariétaux en forment le complément; d'une part, ce serait une composition différente de celle des autres vertèbres, puisque l'anneau serait formé de cinque pièces et même de six, en comptant l'inter-pariétal; de l'autre, il arrive dans plusieurs animaux que les ailes temporales du sphénoïde n'atteignent pas au pariétal, parceque le temporal va toucher au dessus d'elles, soit au frontal soit au sphénoïde antérieur. Ainsi les pariétaux sont des pièces indépendantes du sphénoïde postérieur, des pièces particulières qui ont une destination particulière, celle de servir de bouclier à la partie moyenne et postérieure des hémisphères, tout comme les grandes ailes ont celle de servir de support aux lobes moyens dans lesquels ces hémisphères se terminent vers le bas."—*l. c.* p. 713.

The new functions which the uplifted and independent spines of the parietal and frontal vertebræ perform in man and many mammals are, with respect to the parietal bones, to shield the upper surface of the middle and posterior parts of the cerebral hemispheres, whilst the frontal is confined to covering the anterior lobes of the same hemispheres.

Hereupon it may be asked whether such relations and offices are the rule or only the exception; and, if the latter, whether it occurs in the lowest or the highest of the vertebrate series; whether in that class where the archetypal arrangement of parts is most, or in that in which it is least departed from? All these considerations are felt to be indispensable by the homologist in quest of the true signification of the parts of the animal frame, before drawing his conclusions from the first modification that may present itself. They are neglected by Cuvier in the objection to the vertebral character of Oken's 'kiefer-wirbel,' founded upon the relations which the parietal bones present to the encephalon in the mammalian class. Yet the more normal relations of those bones, both to the encephalon and to the alisphenoids, seem to have been present to the mind of Cuvier, and to have been duly appreciated by him when he defined, in 1817, the second cranial cincture as constituted by the parietals and sphenoid*.

With regard then to the first of Cuvier's arguments for viewing the human and mammalian parietals as 'des pièces particulières qui ont une destination particulière,' viz. that they are separated from the alisphenoids by the temporal bones. If we commence our consideration of it by the question, whether this separation be the rule or the exception, the reply which Nature sanctions will be that they are not so separated in any of the three great classes of oviparous vertebrata, nor in the majority of mammalia, nor even, as a general rule, in man himself. With regard to the second objection founded on the interposition of the enormously and backwardly developed prosencephalon between the mesencephalic spines (fig. 25, 7) and the mesencephalic segment of the brain, to which the parietal vertebra essentially relates,—its value will depend on the choice made by the homologist between the function of the parietals as immediate shields to the optic lobes (mesencephalon) in the cold-blooded classes, and their function as mediate ones through the interposed mass of the prosencephalon in the warm-blooded classes, as that which best manifests adhesion to the ideal archetype. What to me has ever appeared one of the most beautiful and marvellous instances of the harmony and simplicity of means by which the One great Cause of all organization has effected every requisite arrangement under every variety of development, is the fact, that the protection of the enormous cerebrum peculiar to the higher mammals has not been provided for by new bones: by bones, *e. g.* developed from centres so numerous or so situated as to render any determination of their homologies as vague and unsatisfactory as would result from the attempt to determine those of the dermal ossifications upon the head of the sturgeon, in reference to the endoskeletal epicranial bones in fishes and reptiles. We might well have expected, had conformity to type not been a recognizable principle in the scheme of organized beings, to have had so many 'particular bony pieces' and so situated in the expanded human cranium as would have baffled all our endeavours to reduce them to the type of the epicranial bones of the reptile or fish. Yet the researches of the great comparative anatomists of the present century, and more especially those of Cuvier himself, have proved that there is no such difficulty: and a glance at the Table of Special Homologies, No. 1, will show that the bones (3, 7, 11) most modified in relation to the expanded cerebrum and cerebellum of man and mammals are

* Règne Animal, i. p. 73.

precisely those of which the determination has been easiest, and respecting the names and nature of which there has been the least discrepancy of opinion. It is with pain and a reluctance, which only the cause of truth has overcome, that I am compelled to notice the inconsistencies into which the great Cuvier fell, when his judgement became warped by prejudices against a theory, extravagantly and, perhaps, irritatingly, contended for by a contemporary and rival anatomist. After having established by the clearest evidence and soundest reasoning in his great and immortal works that the bones (7) in the fish (figs. 2 and 5) and reptiles (figs. 9, 10, 13, 19, 22) were homologous with those in birds (7, figs. 8 and 23), mammals (7, figs. 12 and 24), and even in man (7, figs. 11 and 25); and, after contending that they ought to bear the same name—under which, indeed, we find him describing them in the 'Leçons d'Anatomie Comparée' from man down to the fish—Cuvier comes at last to declare that, in those animals in which they are separated from the alisphenoids and mesencephalon, they are "particular pieces which have a particular destination!"

The relation of the mastoids (8, 8), as parapophyses, to the parietal or sphenoidal vertebra not having been detected in Cuvier's time, he supposes that the pterygoids, in the system which makes a vertebra of the sphenoid, can be compared to nothing else than the transverse processes of such. As, according to my views, they are recognizable in General Homology as quite distinct elements of another cranial vertebra, the arguments which Cuvier advances in disproof of what he thought they must be called, do not concern the subject of the present Report. The inferior exogenous processes, indeed, of the basisphenoid in mammals are not unlike those developed from the under surface of the centrum of the atlas in *Sudis gigas*, or from some of the cervical centrums in birds. The argument founded by Cuvier on the autogenous development of the true pterygoid (figs. 24 and 25, 24) would weigh little against its parapophysial nature, if other characters concurred to prove it a 'parapophysis;' but its connections and position show it to be a 'diverging appendage.'

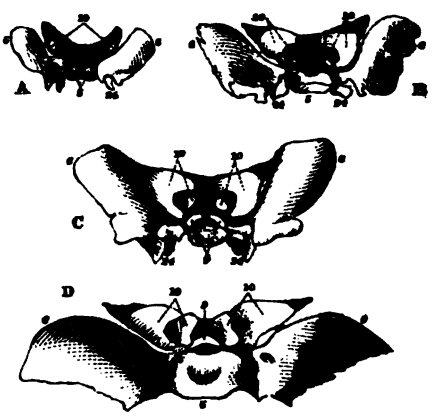
With respect to the anterior sphenoid, Cuvier affirms that its composition is totally different from that of the posterior sphenoid and occipital, and from that of any vertebra. By the term 'sphénoïde antérieure' is meant the coalesced presphenoid and orbitosphenoids (figs. 24 and 25, 9 and 10); and the two bones referred to in the comparison signify, the one, the basi- and alisphenoids (*ib.* 5 and 6), and the other the basi- and ex-occipitals (*ib.* 1 and 2). With respect to 9 and 10, Cuvier remarks that it is never, in mammals, formed of three pieces, but only of two; and that these are properly the bony rings for the optic nerves, which in course of time approximate and coalesce with each other: but so long as the median suture divides them, no distinct or third bony nucleus is developed in the intervening cartilage*.

Since, however, we see that the homologues (recognised as such by Cuvier) of the orbitosphenoids are something more than rings surrounding the optic nerves in the bird (figs. 8 and 23, 10) and crocodile (figs. 9 and 22, 8)—that they are merely notched by the optic nerves, and are chiefly developed in

* "L'on a voulu aussi considérer le sphénoïde antérieur comme une vertèbre dont les frontaux compléteraient la partie annulaire, et où la position du trou sphéno-orbitaire entre les deux sphénoïdes repondrait assez aux trous inter-vertébraux ordinaires. Mais la composition du sphénoïde antérieur lui-même est toute différente de celle des deux os, dont nous avons parlé avant lui, et de celle d'aucune vertèbre. Il n'est jamais, dans les mammifères, formé de trois pièces, mais seulement de deux; ce sont proprement des anneaux osseux pour les nerfs optiques, qui par suite du temps se rapprochent et se soudent entre eux; la suture est toujours au milieu, et tant que l'ossification n'est pas complète, il n'y a entre les deux anneaux que du cartilage, dans lequel il ne se forme pas de troisième noyau."—*l. c.* p. 714.

neurapophysial relation to the sides of the prosencephalon,—we are led to carry our inquiries into an earlier period of their development than that adduced by Cuvier, as contravening their vertebral characters. Cuvier cites the figure 2, in pl. xxxv. of the 'Osteogenia Fœtuum' of Kerkringius, as evidence of his statement of the developmental characters of the 'sphénoïde antérieur." That figure, however, exhibits the condition of the bone, when, although the median suture remains, each orbital ala has become anchylosed with the posterior sphenoid, and is likewise directly perforated by the optic nerve. The gelatinous cells of the anterior extremity of the notochord very early retrograde to the basioccipital region of the basis cranii, and the notochordal capsule alone is continued to the anterior extremity of the basis. This is converted into cartilage, and the osseous particles which ultimately constitute the anterior sphenoid are deposited as follows: first a centre or nucleus appears, in each orbital ala, external to the hole by which the optic nerve passes through the primitive cartilage (fig. 26, A, 10); soon after a second nucleus (*ib.* B, 10) is established at the inner or mesial side of each optic foramen: these centres form the foundation of the neurapophyses or orbitosphenoids, and ultimately coalesce around the optic nerve, as Kerkringius has depicted. But a third pair of ossific centres (*ib.* C, 9) is established behind the optic foramina between these and the basisphenoid (5). This third pair unite together into a single transverse bar (*ib.* D, 9), before coalescing with the orbitosphenoids in front, or with the basisphenoid behind, and that bar transitorily represents the centrum of the frontal vertebra. To the objection that such supposed centrum is developed from two points instead of one, the same reply may be made that was made before to a similar objection raised by Cuvier against the general homology of the basisphenoid; which objection, as was then shown, would be equally valid against the universally admitted homology of the body or centrum of the atlas.

Fig. 26.



Phases of development of the Human Sphenoid bone: after Meckel.

The frontal neurapophyses manifest in their development, each from two centres (fig. 26, B, C, 10), a transitory mark of vegetative repetition analogous to that which permanently characterizes the neurapophyses of the trunk-vertebræ in the sturgeon.

Thus the evidence of development, when complete, tells for, rather than against the serial homology of the 'sphénoïde antérieur' of Cuvier with the centrum and the neurapophyses of other vertebræ; and the more obvious and important characters of relative position to the other bones of their own segment, and to their homotypes in the contiguous segments, as well as to prosencephalic segment and characteristic nerves,—which characters have served to determine the special homologies of the coalesced bones in question (9, 10) from man down to the fish,—concur with the developmental characters in establishing their general homology as centrum and neurapophyses.

Cuvier affirms, however, in support of his argument, that, although the orbitosphenoids are never separated from the frontals, as the alisphenoids are from the parietals, in the mammalia, they are almost always separated from the frontals in the other classes, so that the vertebral ring is again interrupted *. But, were even the frontals commonly uplifted above the orbitosphenoids in birds, reptiles and fishes, which does not accord with my experience, the objection, on that score, to regarding them as 'neural spines,' would as little apply, as it does to the universally recognised general homology of the separated and uplifted neural arch of the first vertebra of the trunk of the *Ephippus* and some other fishes.

Cuvier finally regards the connection of the frontals with the prefrontals, which he calls 'ethmoid' in mammals, 'l'enchâssement de l'ethmoïde,' as a function quite remote from any of a vertebral character, "relative à toute autre chose." This objection only shows the necessity of a right appreciation of special homologies, in order to form a true judgement respecting general homology; and, with respect to the 'ethmoïde,' I must refer to the section on the prefrontals in the chapter on 'Special Homology (p. 214). If the arguments there adduced be held to prove the crista galli and cribriform plate in the human skull to be the homologues of portions of the coalesced prefrontals and olfactory capsules, we may next remark that these portions are not merely wedged between the orbital plates of the frontal, but articulate behind by a persistent suture with the orbitosphenoids. As neurapophyses, the coalesced prefrontals of the terminal vertebra of the skull thus articulate with their next succeeding homotypes; and, by virtue of the excessive development of the spine of the frontal vertebra, as well as from their being contracted and drawn backward in the human skull, they articulate with such spine (the frontal) as well as with that of their own proper segment (the nasals). But, in the crocodile (fig. 9), we have seen a similar relation manifested not only by the more normal neurapophyses (14) of the nasal vertebra, but likewise by those (10) of the frontal, those (6) of the parietal, and those (2) of the occipital vertebra.

All the objections raised by Cuvier to the general homology of the cranial bones as modified vertebral elements, equally apply to elements of vertebræ in the trunk, which Cuvier himself has admitted to be vertebræ, notwithstanding such modifications. The repetition of the perforated character of the human alisphenoid and orbitosphenoid in the neurapophyses of the trunk-vertebræ of many inferior animals, requires only a passing notice. The flattening, expansion and sutural union of the human supraoccipital, parietal and frontal bones, are matched by the neural spines in the carapace of the tortoise. If the basioccipital, basisphenoid and presphenoid are broad and flat, instead of cylindrical, so likewise are the bodies of the sacral vertebræ in the broad-bodied megatherioids and in many birds. If the basioccipital and basisphenoid are lengthened out and firmly united together by deeply indented sutural surfaces in most fishes, so likewise are the bodies of the four anterior vertebræ of the trunk in the pipe-fish (*Fistularia*). If the basisphenoid and presphenoid be developed each from two ossific centres, as in man, so likewise may the body of the human atlas be ossified; and even should the moieties of that centrum not coalesce at the median plane, they would

* "Ce que j'ai dit des pariétaux s'applique aux frontaux, considérés comme compléments du sphénoïde antérieur; leur fonction est relative à toute autre chose, à la protection des lobes antérieurs du cerveau et à l'enchâssement de l'ethmoïde; et quoique le sphénoïde antérieur n'en soit jamais séparé dans les mammifères comme le postérieur l'est souvent des pariétaux, il l'est presque toujours dans les autres classes, en sorte qu'alors l'anneau vertébral serait aussi interrompu."—*l. c.* p. 714.

nevertheless still retain their essential characters as divisions of a single vertebral element: just as does the vomer in the salamanders, salamandroid fishes and serpents, which begins to be developed from two lateral points, like the body of the human atlas occasionally, without the development ending, as it always does in such atlas, by confluence of the resulting halves. It would be more reasonable to repudiate the general homology of the body of a whale's dorsal vertebra with the centrum of the typical vertebra, because it consists of three pieces set end to end, than to deny the general homology of the vomer because it may consist of two pieces set side by side, or that of the anterior trunk-vertebræ of the silurus because they consist of two pieces set one upon the other. These are examples of a principle of variation which Cuvier never permitted to blind his perception of the special homology of certain bones, the mandibular ramus, for example; though vegetative or teleological subdivision is carried out to a much greater extreme there than in any vertebral centrum; unless, indeed, the number of points from which the whale's vomer be ossified may equal those in the crocodile's lower jaw. But if the differences in this developmental character, viz. of ossification from a single ossific point as in the vomer of the cod, or from two points as in that of the lepidosteus, or from three or more points as in the human vomer, interpose no obstacle to the determination of the special homology of the bone is from man to fish, it can as little avail as an argument against its general homology, which is determined not by the development of the vomer but by its relations to the other constituents of the segment of the skeleton to which it naturally belongs.

The great difficulty which the anthropotomist may naturally experience in forming an idea of the vomer as the body of a vertebra, will arise from its extremely modified form in the human subject: but he must bear in mind that it is an extreme part, the last of its series counted forwards; and if he should desire some higher and better established authority than the present Report before yielding assent to the vertebral character of the bone, under its characteristic 'ploughshare' mask in man, I know no name more influential than that of Cuvier himself, in regard to the equally and similarly modified centrum at the opposite end of the vertebral series in the bird. For although the mask of coalescence is superadded to that of strangeness of shape in the bone which Cuvier there compares to a ploughshare [vomer, or 'soc de charrue'], the great anatomist and cautious generalizer does not hesitate to affirm that it is "composed of many vertebræ" (see *ante*, p. 263).

It may, perhaps, be said that the coccygeal vomer must be vertebral in its nature because it is situated in the tail; but the 'petitio principii' in this argument will be transparent, if we transpose the locality, and say that 'the cranial vomer must be vertebral in its nature because it is placed in the head.' For what are 'head,' 'tail,' 'thorax,' or 'pelvis,' but so many diversely modified portions of a great segmental whole? These localities do not determine the nature of the segments composing them; such knowledge can only be acquired by a study of the composition of the segments; and it is the modifications of the segments that determine the nature of the localities or divisions of the endoskeleton, to which such special names as 'head,' 'thorax,' &c. are applied.

Yet Cuvier himself, perhaps, little suspected how much his ideas of the essential nature of a segment of the endoskeleton were governed by the part of the body in which it happened to be placed. Whenever the young anatomist finds a difficulty from the peculiar form or development, division or coalescence, of a cranial bone, in recognising or admitting its vertebral

character, let him compare the results of his own observations with those summed up in pp. 264–266, and see whether the same kind of modification may not be repeated in the homologous element of a vertebra of the trunk in one or other of the species of vertebrate animals.

The latest direct objection to the cranio-vertebral system is from the pen of the celebrated ichthyotomist of Neuchatel. M. Agassiz represents the current ideas respecting this system at the period when he published his objections to it, in the following graphic passage of his invaluable and splendid work:—"It was M. Oken who had printed the first programme on the signification of the bones of the skull. The new doctrine which he set forth was received with extreme enthusiasm in Germany by the school of physio-philosophers [Natur-philosopher]. The author at that time required three cranial vertebræ, and the basioccipital, the sphenoid and the ethmoid were viewed as the central parts of these cranial vertebræ. Upon these pretended bodies of vertebræ were raised the arches enveloping the central parts of the nervous system (our 'protective plates'); whilst to the opposite side were attached the inferior pieces which should form the vegetative arch destined to embrace the intestinal canal and the great vessel (the 'facial arches' of which we shall presently speak). It would be tedious to enumerate here the changes which each author has rung upon this theme in modifying it agreeably with his notions. These contented themselves with the number admitted by Oken; those raised the number of cranial vertebræ to four, six, seven, or even more: some saw nothing but ribs in the branchial arches and jaws; others took the latter for limbs of the head, analogous to arms and legs. If they could not agree about the number of the vertebræ, still less were they at one in regard to the part assigned to each bone. The most bizarre nomenclatures have been proposed by different authors who thus sought to generalize their ideas. Some have gone so far as to pretend that the vertebræ of the head were as complete as the vertebræ of the trunk, and by means of dismemberments, with divers separations and combinations they have reduced all the forms of skull to vertebræ, assuming that the number of pieces was invariable for every form of skull, and that all vertebrate animals, whatever their definitive organization, bore, in their respective crania, the same number of points of ossification *."

And thus it is that a great truth in nature has been endeavoured, and

* "C'est M. Oken qui fit imprimer le premier programme sur la signification des os du crâne. La nouvelle doctrine qu'il exposait fut accueillie en Allemagne avec un enthousiasme extrême par l'école des philosophes de la nature. L'auteur postulait alors trois vertèbres du crâne, et l'occipital basilaire, le sphénoide et l'ethmoide étaient envisagés comme les parties centrales de ces vertèbres craniennes. Sur ces prétendus corps de vertèbres s'élevaient des arcs enveloppant les parties centrales du système nerveux (nos plaques protectrices); tandis que du côté opposé étaient attachées des pièces inférieures qui devaient former l'arc végétatif destiné à embrasser le canal intestinal et les gros vaisseaux (les arcs de la face dont nous traiterons plus tard). Il serait trop long d'énumerer ici les changements que chaque auteur apporta à ce travail en le modifiant à sa manière. Les uns se contentèrent du nombre admis par Oken, les autres élevèrent le nombre des vertèbres craniennes jusqu'à quatre, six, sept et même plus; les uns voulurent voir des côtes dans les arcs branchiaux et les mâchoires; les autres prirent ces dernières pour des membres de la tête, analogues aux bras et aux jambes. Si l'on n'était pas d'accord sur le nombre des vertèbres on l'était encore moins sur le rôle qu'on assignait à chaque os. Les nomenclatures les plus bizarres ont été proposées par les différens auteurs, qui cherchaient ainsi à généraliser leurs idées. On alla jusqu'à prétendre que les vertèbres de la tête étaient aussi complètes que les vertèbres du tronc, et au moyen de démembremens, de séparations et de combinaisons diverses, on ramena toutes les formes du crâne à des vertèbres, en admettant que le nombre des pièces etait invariablement fixé pour toutes les têtes; et que tous les vertébrés, quelle que soit d'ailleurs leur organisation définitive, portaient dans leur tête le même nombre de points d'ossifications." —Recherches sur les Poissons Fossiles, t. i. (1843), p. 125.

too successfully in regard to the rising generation of anatomists, to be obscured. Ideas and statements are misquoted, unintentionally, doubtless, and through neglect of reference to the original work (as in the citation of the bones representing the bodies of the cranial vertebræ in the Okenian theory): or they are misunderstood (as where the arches, neurapophyses or 'bogentheile,' composed as Oken truly said by the alisphenoids and orbitosphenoids are held to be synonymous with the 'plaques protectrices' of M. Vogt): the most extreme and least defensible views are selected out of each tentative step in the inquiry, and are clubbed together to represent the general result, which is of course dismissed with as sweeping a condemnation. The specific objections raised by Cuvier are deemed well-founded and unassailable; and to these M. Agassiz adds the following. Premising that, "the formation of vertebræ presupposes as a first condition the existence of a notochord*;" and, arguing upon this basis, and on the assumption that the cephalic extension of the 'chorda dorsalis' as it is permanently manifested in the *Branchiostoma* is not so great in the embryos of other and higher fishes, but is arrested at the region of the alisphenoid from the commencement of its development, M. Agassiz concludes:—"Now, the application of this principle to the composition of the skull demonstrates at once that there exists *but one cranial vertebra, the occipital vertebra*, and that the rest of the skull is foreign to the vertebral system†."

At the period of development described and figured by M. Vogt in the embryo of the *Coregonus*, which period M. Agassiz conceives to represent the very earliest condition of the anterior extremity of the notochord, the pointed extremity of the gelatinous central cells of this part terminates at the posterior boundary of the hypophysial space: but the peripheral capsule of the notochord extends over that space and forwards to the obtuse anterior extremity of the embryonal 'basis cranii': and it is in the expanded aponeurosis, directly continued from the chorda along the basis cranii, that the thin stratum of cartilage cells are developed, arching along the sides of the hypophysial space, from which the ossification of the basisphenoid, presphenoid and vomer proceeds ‡.

The superaddition or the later continuation of the cylindrical gelatinous 'chorda' in the aponeurotic basis of the cartilaginous and osseous growths of the vertebral centres in the trunk, seems to relate chiefly to their more or less cylindrical form in that region: the notochord regulates, as a mould, the course of ossification, disappearing by absorption as the bony lamellæ of the vertebral bodies encroach upon it in their centripetal progress: the notochord plays an important part also in the establishment of the elastic jelly-filled capsular joints in the back-bone of fishes; and therefore it might well be dispensed with, or be early and rapidly removed, in the development of the flattened, expanded and anchylosed or immoveably articulated bodies of the cranial vertebræ. And, besides, the notochord is immediately concerned in the development of only one of the elements of the typical segment of the endoskeleton. It is obviously, therefore, an unwarrantable and erroneous application of a developmental character, to conclude, from a modification of this one character in respect of a single element, the 'centrum,' that every other character establishing the general homology of such element, as

* "La formation des vertèbres suppose, comme première condition, l'existence d'une 'corde dorsale.'"—*Op. cit.* tom. i. p. 127, livr. xviii. (1843.)

† "Or, l'application de ce principe à la composition de la tête nous montre d'entrée qu'il n'existe *qu'une seule vertèbre crânienne, la vertèbre occipitale*, et que le reste de la tête est étranger au système vertébrale."—*Ib.* p. 127.

‡ Hunterian Lectures on Vertebrata, 1846, p. 71.

well as every character determining that of the surrounding vertebral elements, are to be nullified and set aside! M. Agassiz, moreover, seems not to have suspected that the notochord may have other and more immediate and important functions than even those relating to the vertebral column. The peculiar elective attraction of its component cells for the gelatinous principle may be essential to the due operation of those neighbouring cells which form the basis of the neural axis, and which as exclusively assimilate the albuminous principle: and this reciprocal antagonism in the selection of particular proximate principles from the common primitive blastema may explain the contemporaneous origin of notochord and myelon in the embryonic trace, when all development is as yet the work of cell-assimilation and metamorphosis, without any supply from a vascular system, this being a later formation in the building up of the organic machinery. By confining, however, his views of the notochord to one of its functions in relation to a single vertebral element, and by extending his conclusions from this to the entire vertebra, M. Agassiz, though recognising more absolutely than Cuvier, the vertebral character of the neural arch of the occipital segment, concludes that Nature discards that type in the conformation of the cinctures that precede it and which successively girt the mesencephalon, prosencephalon and rhinencephalon.

Assuming a gratuitous explanation of the hypothetical absence of the bodies of the cranial vertebræ (Poissons Fossiles, t. i. p. 128), M. Agassiz asks, "Ainsi, que seraient dans cette hypothèse, le sphénoide principal, les grandes ailes du sphénoide, et l'éthmoide, qui forment pourtant le plancher de la cavité cérébrale?—Des apophyses?—Mais, les apophyses ne protègent les centres nerveux que du côté et d'en haut?—Des corps des vertèbres?—Mais ils se sont formés sans le concours de la corde dorsale; ils ne peuvent donc pas être des corps des vertèbres." (*lb.* p. 129.) To this it may be replied, first that the bodies of the cranial vertebræ are not absent; they are represented, as above explained, by their cortical portions in the vomer (fig. 5, 12), presphenoid (*ib.* 9) and basisphenoid (*ib.* 3), and by both cortical and central portions in the basioccipital (*ib.* 1): nay, the central part of the body of the frontal vertebra is represented in some fishes by the entosphenoid (*ib.* 9'), which remains distinct from the cortical part below, as does the central part of the body of the atlas in the siluroid fish. If it were true, indeed, that the entosphenoid was pierced by the canals transmitting the olfactory nerves*, Bojanus' idea of its general homology as the centrum of the 'vertebra optica' must be abandoned. But the parts called 'olfactory nerves' by M. Agassiz, pass from the prosencephalic to the rhinencephalic compartments of the cranium not merely above the bone called 'cranial ethmoid' by the same author, but, also, through the upper part of the interspace between the bones (orbitosphenoids) which the entosphenoid (9') sustains: and the true olfactory nerves perforate the neurapophyses (14) which Bojanus called 'ethmoid' and which Cuvier and M. Agassiz have termed 'frontaux antérieurs' (see *ante*, pp. 214–226). The alisphenoids, being notched or perforated by their proper intervertebral nerves, are 'apophyses' (neurapophyses), and accordingly do protect the sides of their proper nervous centre, the mesencephalon. The central jelly-cells of the notochord appear to be withdrawn into the occipital region before ossification of the basisphenoid commences, and that modified vertebral body is therefore developed at the expense of the fibrous sheath of the notochord, and is represented by its 'cortical' part only. But its general homology is determined by its con-

* M. Agassiz has described this bone under the name of 'éthmoide crânien' as "un os impair, court, de forme presque carré dans lequel sont percés les canaux servant aux nerfs olfactifs."—Recherches sur les Poissons Fossiles, t. i. p. 120.

nections with the basioccipital (admitted by Agassiz to be a vertebral body) behind, and with the alisphenoids above.

In many fishes the basisphenoid unites with the basioccipital by a deeply indented sutural surface, like that which unites together the elongated bodies of the anterior trunk-vertebræ in the *Fistularia*. In mammals the basioccipital and basisphenoid join each other by flat surfaces, also like the bodies of the trunk-vertebræ, until the period when, in most of the class, the joint is obliterated by anchylosis. These and similar repetitions of class-characters of vertebral elements in the regions of the head and trunk are not so wholly devoid of signification, as they must seem to be to the opponents of the cranio-vertebral theory.

In his new and elaborate classification of the bones of the skull of fishes, M. Agassiz divides them primarily, like Cuvier, into bones of the *cranium*, or 'box which envelopes the brain and the organs of sense': and into bones of the *face*, 'which is composed of the moveable pieces subservient to nutrition and respiration' (*l. c.* p. 110).

This division is open to the objection that the bony or cartilaginous capsules which immediately envelope the organs of sense are always originally, and most of them permanently, separate from the box or capsule that envelopes the brain. The independent character of the ear-capsules, for example, is manifest on their first appearance in the ammocete; and, although they subsequently lose their distinctive features by the accumulation of cartilage-cells around them in which the foundations of the neurapophyses and parapophyses, contributing to the otocrane, are laid, one centre of ossification is commonly established, even in fishes, in special relation to the immediate protection of the vascular and nervous parts of the labyrinth.

As to the proper bony envelope of the eye, M. Agassiz does not enumerate it amongst the cranial bones of fishes: but admits into that series only the accessory protecting pieces which form the orbit; or rather only those that at the same time form the brain-case: for, the suborbitals, the entopterygoids and palatines are placed amongst the 'facial' bones: whilst the supraorbitals are transferred to another category of osseous pieces, the natural system here prevailing over the artificial one.

Subjoined* is an outline of the arrangement of the two primary classes of 'cranial' and 'facial' bones, founded upon the embryological researches of

* CRANIAL BONES. (OS CRANIENS.)

A. EMBRYONIC BASIS ('*BASE EMBRYONALE*,' Vogt).

a. Nuchal plate ('*Plaque nuchale*,' V.). Basioccipital, Exoccipitals, Paroccipitals, Supraoccipital, Petrosals.

b. Lateral loops ('*Anses latérales*,' V.). Alisphenoids, Orbitosphenoids.

c. Facial plate ('*Plaque faciale*,' V.). Entosphenoid (l'ethmoïde crânien, Ag.).

B. PROTECTIVE PLATES ('*PLAQUES PROTECTRICES*,' V.).

a. Superior plates. Parietals, Frontals, Nasals.

b. Lateral plates. Prefrontals, Postfrontals, Mastoids (temporaux, Ag.).

c. Inferior plates ('*Plaque buccale*,' V.). Basi- pre- sphenoid, Vomer.

FACIAL BONES. (OS DE LA FACE.)

I. *Maxillary arch.* Suborbitals (jugaux, Ag.), Maxillary, Premaxillary.

II. *Palatine arch.* Palatines, Entopterygoids, Pterygoids (transverses, Ag.).

III. *Mandibular arch.* Pretympanics ('caisses,' Ag.), Mesotympanics ('tympano-malleaux,' Ag.), Hypotympanics ('os carrés,' Ag.), Mandible.

IV. *Hyoidean arch.* Epitympanics ('mastoïdiens,' Ag.), Preoperculars, Stylohyals, Epihyals, Ceratohyals, Basihyals ('l'os lingual,' Ag.).

V. VI. VII. VIII. *Branchial arches.* 'Composés chacun de deux ou trois pièces et reunis sous le gorge par le corps de l'hyoïde.'

IX. *Pharyngeal arch.* 'Composé d'une ou de plusieurs pièces,' &c.—*Op. cit.* t. i. pp. 124, 130.

M. Vogt. With regard to the series of nine arches into which the facial bones are distributed, it may be remarked that the independence of the maxillary from the palatine, which is more apparent than real in the osseous fishes, ceases to be manifested in any degree in the plagiostomes and lepidosiren: that the first and second arches are suspended by their crowns with their haunches projecting freely outwards, whilst the third and fourth arches are suspended, in the reverse position, viz. inverted, with the crowns or key-stones downwards: the four next arches are rather complete cinctures, their summits meeting and being loosely suspended to the basis cranii, or, in plagiostomes and cyclostomes, to the under part of the vertebral column of the trunk. Although professing to base his classification upon developmental characters, M. Agassiz owns with regard to the posterior branches of the maxillary arch, *e. g.* the suborbitals, "that they appear to be rather formed by the dermal system." And this is unquestionably true: whilst the palatines, which are the true piers of the arch, are developed from the blastema of the same visceral arch as the maxillaries and premaxillaries.

The error in regard to the special homology of the suborbital bones, determined by M. Agassiz as the malars, and which is so clearly exposed by the structure of the skull of the *Psittacidæ* (*ante*, p. 209), has misled him in respect to the natural and typical constitution of the maxillary arch.

The mistake in reference to the special homology of the epitympanic (*sa*), determined by M. Agassiz as the 'mastoid,' has, in like manner, influenced him in dissociating it from the other dismemberments of the tympanic pedicle, and referring it to a different arch.

With regard to the hyoid and branchial arches, it will be observed that M. Agassiz makes no distinction between the systems of the neuro- and splanchno-skeleton. An arch constant and ossified in all vertebrates where the rest of the endoskeleton is ossified, and which, even admitting M. Agassiz' special homology of the preopercular as the styloid process of the temporal, would still be suspended in the inverted position, like a true hæmal arch, is placed in the same category as the branchial girdles, which are often cartilaginous when the hyoid is osseous, in bony fishes; and which disappear, in the metamorphosis of the tadpole, with the evanescent respiratory viscera for the support of which they are exclusively developed.

The constitution of a distinct 9th facial arch for the posterior pair of branchial girdles, which retain their gills in lepidosiren, though modified in subservience to mastication in most osseous fishes, appears to be giving undue importance to an artificial or adaptive character. Finally, the natural connections of the scapulo-coracoid arch in osseous fishes are totally disregarded, and it is left out of the enumeration of the bones of the head.

The unbiassed anatomist may find an element for judging of the natural character of the cranio-vertebral system propounded in the present Report, by contrasting the classification of the bones of the fish's skull to which it leads, with that proposed by M. Agassiz, and with nature*.

Having thus responded to the objections advanced by Cuvier and M. Agassiz to the interpretations of the segmental constitution of the bones of the head which were open to the criticism of those great authorities in anatomy, I proceed briefly to explain the segmental constitution of the bones

* I am bound here to say that in the discussion of the subject of this Report with M. Agassiz, which, amongst other advantages of the meetings of the British Association, I enjoyed at Southampton, he admitted, with his characteristic frankness, that some points of his classification of the bones of the head in fishes would require reconsideration. One of the eminent physiologists who was present at the debate which followed the reading of the Report, has recorded the impression it produced upon him in a review of my 'Hunterian Lectures on Vertebrata' in 'The British and Foreign Medical Review,' No. xlvi. p. 490.

of the trunk of the human subject according to the archetype with which the segments in the head have been illustrated.

The first seven segments of the trunk consist each of centrum (fig. 25, *c*), neurapophyses (*n*), neural spine (*s*), and rudimental pleurapophyses (*pl*), which coalesce, in each segment, into one bone, called 'cervical vertebra' in anthropotomy. If the hæmapophyses (*ss'*) have the same relation to their centrum which those of the seventh dorsal vertebra, in the *Cicenia Argala*, more obviously bear to theirs,—that is, being attached below and disunited at their upper ends from their pleurapophyses, which are short, stunted and anchylosed to the centrum,—and if, as the apparent homologues of *ss'* in fishes would indicate, the atlas be actually the centrum to which such detached and shifted hæmapophyses belong, then the first will be the sole segment of the cervical region of the trunk in which those elements are ossified.

In the seven vertebræ which succeed the cervicals the pleurapophyses (*pl*) are progressively elongated; they are shifted from their proper centrum to the interspace between it and the next segment above, or in advance, and retain their moveable joints. The hæmapophyses (*h*) are cartilaginous and articulate with the ends of the pleurapophyses and with the hæmal spines (*hs*), which are flattened, slightly expanded, and ultimately blended into one bone called 'sternum.' The hæmal spine of the first typical segment remains longest distinct: it receives, also, the extremities of the displaced hæmapophyses (*ss'*) and has been called 'manubrium sterni.' The hæmal spine of the seventh segment commonly continues longer distinct, and is later in becoming ossified, whence it is called 'ensiform cartilage': it probably includes the rudiments of some succeeding hæmal spines. In the four succeeding segments the pleurapophyses become progressively shorter, and the hæmapophyses, still cartilaginous, are severally attached by their lower attenuated ends to the pair in advance; leaving the hæmal arch incomplete below. In the next vertebra (19th from the skull) the still shorter pleurapophyses resume the exclusive articulation with their proper centrum; and the correspondingly short and pointed hæmapophyses terminate freely.

Those pleurapophyses and hæmapophyses which directly articulate with hæmal spines (sternum) are called collectively 'true ribs' (costæ veræ), the proximal element being 'the bony part of the rib' (pars ossea costæ), the distal one the 'cartilage of the rib.' The rest of the hæmal arches which are incomplete through the absence of the hæmal spine, are called 'false ribs' (costæ spuriæ); and the last, which terminates freely in the origin of the diaphragm, is a 'floating rib.' The centrum, neurapophyses and neural spine of each segment with freely articulated pleurapophyses coalesce into one bone, called 'dorsal vertebra' in anthropotomy: these vertebræ are twelve in number. Each of the five succeeding segments is represented by the same elements (centrum and neural arch) coalesced that constitute the so-called dorsal vertebræ: they are called 'lumbar vertebræ' (fig. 25, L.): they have no ossified pleurapophyses; and the hæmapophyses of these segments are represented only by the aponeurotic 'inscriptiones tendineæ musculi recti' (*h''*).

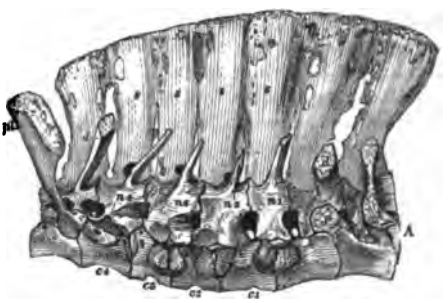
Certain elements of the five succeeding segments (*ib.* S.) coalescing together in the progress of growth form the bone called 'sacrum': and are described individually as sacral vertebræ. The first four of these each combine the same elements, coalesced, as in the neck; viz. centrum, neurapophyses, neural spine, and short but thick pleurapophyses*: in the fifth sacral vertebra there are no

* J. Müller notices the rudimental ribs in the first and second sacral vertebræ of the human fœtus in his Anatomie der Myxinoiden, heft i. 1834, p. 240. Mr. Carlile has described (Report of British Association, 1837, p. 112), and Dr. Knox has figured (Lancet, 1839, p. 191) these ribs and their homotypes in the third and fourth sacral vertebræ.

osseous rudiments of pleurapophyses; and the neural spine is commonly undeveloped. One or more typical segments are obviously completed by the meeting of the broad sides of the inverted arch (62, 63, 64) at the 'ischiopubic symphysis' forming the 'pelvis' of anthropotomy. Before, however, entering upon the difficult inquiry into the general homology of the pelvis, I would beg to refer the reader to the analysis of the sacrum of the ostrich given at p. 263: and I here subjoin a figure of seven of those vertebræ, from an immature specimen, the pleurapophyses being removed from all save the last (*pl*), in order to show the change of place of the neurapophyses *n* 1–4, in relation to their centrums, *c* 1 to 4: *d d* are the long diapophyses; *p* the short parapophyses. The sacral spines, *s s*, are enormously developed.

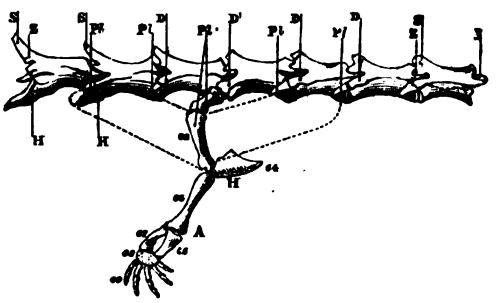
In the bird the modification of the vertebral segments at the posterior region of the trunk in relation to the transference of the whole weight of the body and fore-limbs (wings) upon the hind-limbs, is greater and more extensive than in the 'bipes implume,' and the essential nature of the pelvic arch is still more masked in the bird than in man. In order to obtain an insight into the model according to which it is constructed, we must descend still lower, even to the humblest of the vertebrated creatures that crawl upon the earth. The example which is here selected for that purpose is the perennibranchiate amphibian called *Menopome Alleghanniensis*.

Fig. 27.



7 sacral vertebræ of a young ostrich (*Struthio camelus*).

Fig. 28.



Sacral vertebra and appendage with contiguous vertebræ. Menopome.

The three anterior vertebræ which answer in position to the 'lumbar' in fig. 25, differ chiefly in having rudimental pleurapophyses (*Pl*) articulated to the ends of the diapophyses (*D*). In the next vertebra the diapophysis (*D'*) and the rudimental pleurapophysis (*Pl*) are thickened and enlarged: a second pleurapophysial rib-like piece (62) is joined by one end to the pleurapophysis, and by the other to a broad partially ossified cartilage (64) which meets and joins its fellow, completing a hæmal arch and restoring the vertebra in question to the typical character. A radiated appendage, moreover, diverges on each side from the articulation between 62 and 64, and forms the hind-limb. Now the special homology of this limb with the undivided filamentary appendage similarly situated in the lepidosiren, and with the ventral fins of fishes, in the descending series; and with the hind-limb of other reptiles, of birds and of mammals in the ascending series, is unmistakeable, and, I believe, is generally admitted: so that comparative anatomists have not hesitated to call the rib-like bone, 62, 'ilium,' and the part, 64, 'pubis' in the men-

The special homologies of these elements of the pelvis being thus determined, it follows, that their general homology, as it may be revealed by the simple condition of the pelvic arch in the species in which the pelvis, as complete and fixed to a sacrum, makes its first appearance in the animal kingdom, will be equally applicable to the parts under all their metamorphoses in the higher air-breathing vertebrates.

The correspondence of the segment of the endoskeleton in the menopome D′, Pl′, H, A, with the typical vertebra, as illustrated by fig. 15, is such, that any other explanation of its essential nature than as a representative or repetition of such fully developed segment or vertebra seems contrary to nature. The chief modification has its seat in the most peripheral part or appendage A, as compared with its simple homologue in the thoracic segment of the bird (fig. 15). If o_2 and o_4 are to be regarded as strangers to the vertebral system, new parts introduced for special purposes, and not as normal elements modified for special purposes, I am at a loss to know on what principles, or by what series of comparisons we can ever hope to attain to the higher generalizations of anatomy, or discover the pattern according to which the vertebrate forms have been constructed. It may be said that the arch which they constitute performs a new function, inasmuch as it sustains a locomotive limb which reacts upon the ground. But this new function arises in the menopome, rather out of the modifications of the appendage than of the arch itself. In so far as the mere support of the appendage is concerned, the inverted or hæmal arch Pl′, H, performs no new function, but one which is common to such arches in the thorax of birds, and to the less completely ossified homologous arches in the abdomen of fishes, where moreover the simple diverging appendages do give attachment to the muscles of locomotion. Comparing, then, the hæmal arch in question with that of the typical vertebra (fig. 15), we find that, like the scapulo-coracoid arch in fishes (fig. 5, H 1), its parts are open to two interpretations. The upper piece of Pl' may be the whole pleurapophysis, the lower, o_2, the hæmapophysis, and the part, o_4, the half of an expanded and bifid hæmal spine: or Pl' with o_2, may be two portions of a teleologically compound pleurapophysis, and o_4 the hæmapophysis, which would join with its fellow without, or with a mere rudiment of, a hæmal spine intervening. From the analogy of the scapulo-coracoid arch in fishes, which is proved by its modifications in higher animals to want the hæmal spine, it is most probable that such is the condition and true interpretation of the correspondingly simple pelvic arch under consideration. But the general relation of this arch to the hæmal one of the typical segment is not affected by the alternative.

I regard, therefore, Pl', o_2, as two portions of a fully developed pleurapophysis; and the pleurapophyses, Pl', Pl of the contiguous vertebræ as answering only to the upper portion of the pelvic one. In ascending from the menopome to the crocodile, we find the homologue of o_2 broader than it is long, and articulated to the thickened proximal portions of the pleurapophyses of two segments; and we observe, likewise, the pelvic arch completed below by two pairs of hæmapophyses: for the anterior pair the name of 'ossa pubis' is retained; to the posterior pair that of 'ischia' is given. In general homology these bones complete, as hæmapophyses, the two vertebral segments modified to form the sacrum of the crocodile; and the intermediate connecting piece (ilium) may be interpreted, as either the confluent distal portions of the pleurapophyses of both vertebræ, or as an expansion of one such portion, answering to o_2 in the menopome, and intruding itself between the stunted pleurapophysis and distant hæmapophysis of the second sacral vertebræ in the crocodile.

In the bird the expansion of the element 62 proceeds to a further extent, and besides the proximal piece of the pleurapophysis of its own segment 62, is brought into connection with the homologous stunted or proximal ends of pleurapophyses of several contiguous segments, in the manner indicated by the dotted line in fig. 28. Now, if the ilium, so expanded, were interpreted as the coalesced complementary portions of all the short pleurapophyses with which it articulates, its condition would be very similar to that which Oken has attributed to the scapula. But its ossification radiates, as in the simple rib-like ilium of the menopome, from a common centre: there are no corresponding multiplications of hæmapophyses below; these are restricted in the pelvis of all animals to the number which they present in the crocodile. And since the scapula has been proved to be, under its most expanded form, the homologue of a single pleurapophysis, so also I am disposed to regard its homotype, the ilium, as maintaining under every variety of form and proportion, the same fundamental singleness of character, as it presents on its first appearance in the perennibranchiate batrachian.

The first sacral vertebra, then, in man is complete; but its pleurapophysis is divided, and the lower portion expanded to form the so-called 'ilium' (62). The hæmapophysis (64) coalesces with that of the succeeding vertebra (63), and with its own pleurapophysis (62).

The second sacral vertebra has its hæmapophysis (63, called 'ischium') ossified, but separated from its proper pleurapophysis by the expanded (iliac) portion of that of the preceding vertebra, with which it coalesces, as well as with the preceding hæmapophysis (pubis). The short and thick pleurapophyses of the third sacral vertebra also articulate in the adult with the expanded distal portions of those of the first sacral vertebra: but these (iliac bones) are restricted in infancy and early childhood to their connections with the first and second sacral vertebræ, which connections are permanent in most reptiles.

The fourth sacral vertebra consists of centrum, neurapophyses, and rudimental pleurapophyses; the fifth sacral vertebra of centrum and rudimental neurapophyses, which rarely meet above the neural canal.

In each sacral vertebra the elements of the neural arch and rudimental ribs first coalesce together; and afterwards the vertebræ unite with each other and form the anthropotomical bone called 'sacrum.'

The first coccygeal vertebra in man consists of a centrum and of stunted neurapophyses* wide apart above, but developing zygapophyses, which join those of the last sacral vertebra, and diapophyses which extend outwards further than those of the same vertebra. The neurapophyses are represented by exogenous tubercles of bone in the second coccygeal vertebra; and the third and fourth vertebræ are reduced to the centrums only.

The cartilaginous deposits in the primitive blastema of this extremity of the trunk indicate a greater number of caudal vertebræ, and the rudimental tail is proportionally longer in the embryo than in the adult. It is shortened, however, by absorption prior to the commencement of ossification, and but four segments are indicated by depositions of the earthy salts in the situations proper to the above-specified elements of a typical vertebra: these finally coalesce into a single bone "of a crooked pyramidal figure," which got its name of 'os coccygis' from its supposed resemblance to a cuckoo's beak †.

The early recognition of these and other specialities arising out of the various adaptive modifications of the typical segments of the human skeleton found its expression, necessarily, in special terms, the convenience of which

* "Shoulders of the os coccygis."—Monro, *l. c.* p. 142. † *Ib.* p. 141.

will ensure their permanence; but the course of anatomical science having unfolded the primary form which is the basis of those modifications, there arises the same necessity for giving utterance to ideas of the generic character of the parts by general terms.

Inasmuch, however, as the different segments of the human skeleton deviate in various degrees from the common archetype, and as the different elements of such segments differ in their modifiability, anthropotomy has at no period wanted also its 'general terms' expressive of the recognised extent of such conformity: such terms also, indicating, obscurely indeed, so much perception of the pre-existing model as could be obtained from the study of one form, at a period when that form—the human frame—was viewed as something not only above, but distinct from, if not antithetical to the structures of the brute creation, and when it was little suspected that all the parts and organs of man had been sketched out, in anticipation, so to speak, in the forms of the inferior animals. Thus the word 'vertebra' shows, by the number of the segments or parts of segments to which it is applied in anthropotomy, the recognition of the obvious extent to which the archetype is retained in such primary constituents of the human endoskeleton. And, inasmuch as in some regions (the cervical, *e.g.*) the 'vertebra' includes all the elements of the typical segment, there developed, it has been retained, but, with a more definite meaning, as the technical term of the primary constituent segment of the endoskeleton in all vertebrate animals.

The 'true vertebræ' of anthropotomy are those segments which retain the power of moving upon each other; and the term is applied in a peculiar and empirical sense very different from the meaning which the anatomist attaches to a true or typical vertebra. The 'false vertebræ' of anthropotomy are those segments or parts of segments forming the lower or hinder extreme of the endoskeleton, and which do not admit of reciprocal motion at their joints. And Monro, admitting that the condition of even the human os coccygis sometimes militates against the definition, meets the objection by arguing for the speciality of that bone, and with as good or better reason than those who have subsequently contended against admitting the cranial segments into the category of vertebræ. "From the description of this bone" (os coccygis), "we see how little it resembles *vertebræ*; since it seldom has processes, never has any cavity for the spinal marrow, nor holes for the passage of nerves*."

Embryology has since demonstrated that the parts of the os coccygis are originally in vertebral relation with the neural axis; and that this is subsequently withdrawn by a concentrative movement, which in like manner withdraws it from the terminal segment at the opposite extreme of the endoskeleton. The homology of the divisions of the sacrum with the true vertebræ is admitted by Monro, because of the perforations for the nerves: and this character is still retained in the nasal vertebra in the form of the cribriform foramina, although its neurapophyses, like those of the sacrum, have lost their primitive relation to the neural axis.

Homological anatomy, therefore, teaches, that the term 'vertebra' should not only be applied to the segments of the human skeleton in the technical and definite sense illustrated by figs. 14 and 15, but be extended to those modified and reciprocally immoveable segments which terminate the endoskeleton superiorly, and are called collectively 'skull.'

The term 'head,' then, indicates a region of specially modified vertebræ, like the terms 'neck,' 'chest,' 'loins,' &c.; and amongst the species of the primary segments characterized by specific modifications, the 'cranial' vertebræ must

* Monro, *l. c.* p. 143.

be added to the 'cervical,' 'thoracic or dorsal,' 'lumbar,' 'sacral,' and 'coccygeal or caudal.'

Such, with reference to the 'general' term 'vertebra,' seems to be the advance of which anthropotomical science is susceptible, in order to keep progress and be in harmony with anatomy.

As to the elements of the typical vertebra, anthropotomy has also its general phrases (see Table II. column vi. 'Soemmerring.'), some of which are equivalent to the clearly defined technical terms of such elements in anatomy properly so called.

The serial homology of the centrum (*corpus vertebræ*) has been recognised in all the so-called 'true vertebræ,' and in some of the 'false vertebræ:' thus Monro says, "The fore-part of the *os sacrum*, analogous to the bodies of the true vertebræ, is smooth and flat*." But their smooth and flat homotypes in the skull have only the special names of 'basilar' and 'cuneiform' processes; of 'processus azygos' and 'vomer.' The 'neurapophyses' are recognised as repetitions of the same part under the definitions of 'a bony bridge produced backwards from each side of the body of the vertebra,' of '*arcus posterior vertebræ*,' of 'vertebral laminæ' or 'pedicles.' Monro describes these rudimental elements in the last sacral vertebra as 'knobs,' and in the first coccygeal vertebra as its 'shoulders.' In the skull they receive the special definitions of "the pieces of the occipital bone situated on each side of the great foramen; from which nearly the whole condyles are produced†" (*partes laterales seu condyloideæ*, Soem.); 'great' or 'temporal wings of the sphenoidal bone‡;' 'orbitar wings' or 'processes of the sphenoidal bone;' 'nasal' or 'vertical plate' and 'cristi galli' of the ethmoid ('*pars media ossis æthmoidei*,' Soem.).

The neural spines are called generally '*spinal processes*' in every segment of the trunk: in the head they are known only by the special names of 'occipital plate,' 'parietal bones,' 'frontal bone,' 'nasal bones.'

The pleurapophyses, when free, long, and slender, are called '*ribs*,' 'vertebral ribs,' or 'bony parts of the ribs'; when short and anchylosed, they are called, in the neck, "the second transverse processes that come out from the sides of the body of each vertebra§;" (*radix prior processus transversi vertebræ*, Soem.;) in the sacrum 'transverse processes' and 'ilium'; in the skull, 'scapula', 'styloid process of the temporal bone,' 'external auditory or tympanic process of the same bone'; 'palatine bone.'

In like manner the serial homology of the hæmapophyses is recognised in the thoracic region by the general term 'cartilages of the ribs' or 'cartilages of the sternum' there applied to the same elements of twelve successive segments. When ossified in other vertebræ they have received the special names of 'ischium,' 'pubis,' 'coracoid process of the scapula,' 'clavicle,' 'appendix or lesser cornua of the hyoid bone,' ('*crura superiora*,' '*os linguale superius*,' Soem.), 'lower jaw' or *mandibula*, 'upper jaw' or *maxilla*.

The exigences of descriptive anthropotomy and its highly important applications to Medicine and Surgery necessitate such special nomenclature, and the reform which that nomenclature chiefly requires is the substitution of names in the place of phrases for the parts of the human body.

But the retention and use of specific names for specially modified elements in the different segments by no means precludes the entertainment of general ideas and the necessity of expressing them by generic names for the homologous elements in the entire series of vertebræ.

If anthropotomy is to make corresponding progress with anatomy, and to derive the same light from the generalizations of zootomical science which

* Monro, *l. c.* p. 138. † *L. c.* p. 76. ‡ *L. c.* p. 86. § *L. c.* p. 126.

medical botany has done from general botanical science, its nomenclature must expand to receive those generic terms which express the essential nature of the parts, heretofore named and known only according to the results of particular and insulated observation. A term which truly expresses the general homology of a part enunciates the most important and constant characters of such part throughout the whole animal series, and implies therefore a knowledge of such characters in that part of the human body, when used and understood by the human anatomist. Before the cuneiform process of the occipital bone could be defined as the 'occipital centrum,' the modifications and relations of the homologous part in all classes of vertebrate animals had to be accurately determined. The generic homological term expresses the sum or result of such comparisons, and the use of such terms by the anthropotomist implies his knowledge of the plan or pattern of the human frame which lies at the bottom of all the modifications that raise it to an eminence so far above those of all other vertebrate animals.

In no species, however, is each individual segment of the endoskeleton so plainly impressed with its own individual characters, as in Man; the practised anthropotomist, for example, will at once select and name any given vertebra from either the cervical, the dorsal, or the lumbar series. During that brilliant period of human anatomy which was illuminated by a Fabricius, an Eustachius, a Fallopius, and a Laurentius, the terms expressive of the recognition of such specific characters were more numerous and often more precise than in our modern compilations. Pleurapophyses were individualized in the thorax as well as in the head: the 'antistrophoi,' 'stereai' and 'sternitides,' for example, were distinguished from the other 'pleurai gnesiai'*.

General anatomical science reveals the unity which pervades the diversity, and demonstrates that the whole skeleton of man is the harmonized result of essentially similar segments, although each segment differs from the other, and all vary from their archetype.

Part III.—Serial Homology.

Since, then, we are led by the observations, comparisons and reasonings recorded in the preceding parts of this Report, to recognise, as the fundamental type of the vertebrate endoskeleton, a series of segments repeating each other in their essential characters, it follows that, not only the power of determining the homologous bones throughout the vertebrate series, but also throughout the vertebral segments of the same individual, is included in such generalization.

The recognition of the same elements throughout the series of segments of the same skeleton I call 'the determination of serial homologies.' This kind of study appears to have been commenced by the gifted Vicq d'Azyr, in his 'Mémoire' entitled "Parallèle des os qui composent les extrémités," printed in the Mémoires de l'Académie des Sciences for the year 1774, and Condorcet, in his Report on this ingenious Essay, speaks of it as "un essai d'une autre espèce d'Anatomie comparée, qui jusqu'ici a été peu cultivée."

Vicq d'Azyr compares, or points out the serial homology of, the scapula with the ilium, the humerus with the femur, the two bones of the fore-arm with the two bones of the leg, the small bones of the carpus with those of the tarsus, the metacarpus with the metatarsus, and the fingers with the toes. He is not so happy in his particular as in his general determinations: his

* Anatomica Humani Corporis, &c., multis controversiis et observationibus novis illustrata. Andr. Laurentio, fol. 1600, p. 95.

choice in the leg, for example, of the homotypes of the radius and ulna in the fore-arm, is erroneous; but the whole memoir is an admirable example of the appreciation of correspondences which later researches in the same direction have proved to flow from a higher and more general law of uniformity of type. It is, indeed, a striking instance of the secret but all-prevailing harmony of the vertebrate structure that serial homologies should be determinable to such an extent in the parts of the diverging appendages, which are the seat of the greatest amount and variety of deviations from the fundamental type.

It will, of course, be obvious that the humerus is not 'the same bone' as the femur of the same individual in the same sense in which the humerus of one individual or species is said to be 'the same bone' as the humerus of another individual or species. In the instance of serial homology above-cited, the femur, though repeating in its segment the humerus in the more advanced segment, is not its namesake, not properly, therefore, its 'homologue'. I propose, therefore, to call the bones so related serially in the same skeleton 'homotypes,' and to restrict the term 'homologue' to the corresponding bones in different species, which bones bear, or ought to bear, the same names.

In the skull those bones are homotypes, or repetitions of the same essential part in the series of vertebral segments, which succeed each other lengthwise, as in the last four columns of the subjoined Table:—

Vertebræ.	Occipital.	Parietal.	Frontal.	Nasal.
Centrums	Basioccipital	Basisphenoid	Presphenoid	Vomer.
Neurapophyses	Exoccipital	Alisphenoid	Orbitosphenoid	Prefrontal.
Neural spines	Supraoccipital	Parietal	Frontal	Nasal.
Parapophyses	Paroccipital	Mastoid	Postfrontal	None.
Pleurapophyses	Scapula	Stylohyal	Tympanic	Palatal.
Hæmapophyses	Coracoid	Ceratohyal	Articular	Maxillary.
Hæmal spines	Episternum	Basihyal	Dentary	Premaxillary.
Diverging appendages	Fore-limb or fin	Branchiostegals	Operculum	Pterygoid and Zygoma.

Thus the basioccipital, basisphenoid, presphenoid and vomer are homotypes with the centrums of all the succeeding vertebræ. The exoccipitals, alisphenoids, orbitosphenoids, and prefrontals, are homotypes with the neurapophyses of all the succeeding vertebræ. The paroccipitals, mastoids and postfrontals are homotypes with the transverse processes of all the succeeding vertebræ. The supraoccipital, parietal, frontal and nasal are homotypes with the vertebral neural spines.

The petrosals, sclerotals, and turbinals are homotypes of each other, as being respectively sense-capsules of the splanchno-skeleton.

The suprascapula and scapula are together the homotypes of the stylohyal and epihyal; of the tympanic, whether simple or subdivided, and of the palatal: and all these are the homotypes of the pleurapophyses collectively, whether modified as ribs, hatchet-bones, or iliac bones, in the rest of the vertebral segments.

The coracoid is the homotype of the ceratohyal, this of the articular division of the mandible (with its subdivisions called angular, sur-angular and coronoid, in cold-blooded animals), and this, again, of the maxillary bone: all four being homotypes of the hæmapophyses of the remaining vertebral segments, whether modified to form clavicles, pubic bones or ischia, chevron-bones, sternal ribs, abdominal ribs, cartilages of ribs, abdominal cartilages or tendinous intersections of the modified intercostal muscles called 'recti abdominis.'

The entosternal, when present, is the homotype of the basihyal, of the dentary or premandibular, and of the premaxillary bones; and these collectively are homotypes of the hæmal spines of the rest of the vertebral seg-

ments, whether retaining their spinal shape as in the caudal hæmapophyses, or flattened as ordinary 'sternal bones,' or expanded and subdivided, like the neural spines in the cranium, in order to complete below the thorax of the bird or to form the plastron of the turtle.

There reigns a beautiful parallelism in the kind and degree of modification of the parts of the neural with the corresponding parts of the hæmal arch of the same vertebral segment: and as the serial homologies which have just been enunciated succeed each other longitudinally (horizontally in beasts, vertically in man) in the axis of the vertebral column, so these manifest themselves in a direction perpendicular to that axis.

The manubrium sterni of the bat developes a spine downwards, as the supraoccipital of the fish sends a spine upwards: the expanded manubrium sterni of the whale repeats the condition of the supraoccipital in birds and mammals. The form of the ordinary sternal bones in mammals is repeated by the parietal and supraoccipital bones of the crocodile. The divided sternum of the young ostrich, before the two lateral ossifications have coalesced at the median suture, repeats the condition of the divided parietal in most mammals. The development of the crista from the obliterated suture of the lateral halves of the expanded hæmal spine in the thorax of birds is paralleled by the development of the crista from the obliterated suture of the expanded neural spine in the cranium of carnivores. The interposition of the entosternal piece in the chelonian carapace parallels below the interposition of the interparietal bone in the rodent cranium above.

Thus modifications and developments of the same kind and degree manifest themselves in the upper (neural) as in the lower (hæmal) peripheral elements of the vertebræ; and though not always in the same vertebra, nor in the same animal, yet they are sufficiently exemplified in the myelencephalous series generally, to establish the conclusion that the hæmal spines under all their modifications are vertical homotypes, not of the centrums, as Oken, Meckel and De Blainville have supposed, but of the neural spines of the same vertebræ. In the composition of the neural arch of the occipital, parietal and frontal vertebræ, we find the neurapophyses repeating the pleurapophyses of the hæmal arch, and the parapophyses repeating the hæmapophyses in their relative positions to the centrum and the spine or key-bone of such arches.

Symmetry or serial homology of parts of the same vertebral segment is usually still more strictly preserved in the transverse direction, and is so obvious, as to have immediately led to the detection of the homologous parts, which are accordingly distinguished as 'right' and 'left.'

To return to the consideration of those serial homologies with which Vicq d'Azyr commenced the study of these relations, I may remark that the bones of the fore- and hind-limbs of some of the marsupial quadrupeds best illustrate the true relations which my revered Preceptor in Anatomy, Dr. Barclay* was, I believe, the first to enunciate in respect of the bones of the fore-arm and leg.

The skeleton of the *Phalangista* or *Phascolomys* plainly demonstrates that the tibia is the homotype of the radius, and that the fibula is the homotype of the ulna. In both wombat and ornithorhynchus the fibula assumes those

* In his explanations of Mitchel's Plates of the Bones, 4to, 1824, pl. 24, figs. 3 and 4, Dr. Barclay, without referring to Vicq d'Azyr's Memoir, simply enunciates the correct view of the serial homology of the bones of the fore-arm and leg, as follows:—"On comparing the atlantal (pectoral) and sacral (pelvic) extremities, the fibula is found to be the bone corresponding to the ulna; and accordingly, upon extending our researches to Comparative Anatomy, we perceive it exhibiting the like variety and unsteadiness of character, sometimes large, sometimes small, and sometimes merely a process of the tibia," &c. He does not push his comparison to the bones of the distal segment of the limbs.

proportions and developes that process from its proximal end, the want of which in man and most mammals deceived Vicq d'Azyr, as it has misled, more recently, M. Cruvelhier. The complex explanation of the serial homologies of the bones of the upper and lower extremities proposed by the last named pains-taking anthropotomist*, involves more unnatural transpositions and combinations of the parts than those of the D'Azyrian hypothesis, which its ingenious author could not but admit seemed paradoxical; viz. that the anterior member of one side of the body repeated or corresponded with the posterior member of the opposite side. Cuvier, however, seems to sanction this idea by repeating the statement of Vicq d'Azyr, "C'est la droite d'une paire, qu'il faut comparer à la gauche de l'autre†."

M. Flourens has exposed in detail the fallacies of this view in an excellent memoir in the 'Annales des Sciences' for 1838 (t. x. p. 35); in which he arrives at the same conclusions as Dr. Barclay, and from similar considerations from Comparative Anatomy, as to the serial homologies of the bones of the fore-arm and leg; and he confirms those of the carpal and tarsal bones, which had been so truly and acutely discerned by Vicq d'Azyr.

In mammalian quadrupeds generally the fore-limb takes the greater share in the support, the hind-limb in the propulsion of the body. The *manus* is accordingly commonly shorter and broader than the *pes*; this may be seen in the terminal segment of even the monodactyle hand and foot of the horse. Consequently the transverse direction prevails in the arrangement of the carpal bones and the longitudinal in that of the tarsal bones.

The difference is least in the carpus and tarsus of the long and slender fore- and hind-hands of the quadrumana. If the carpus of the chimpanzee, for example, be compared with that of man, the first difference which presents itself is the comparatively small proportion of the scaphoid which articulates with the radius, as compared with that in man, in whom the distal articulation of the radius is equally divided between the scaphoides and lunare which are on the same parallel transverse series. In the chimpanzee and orang, on the contrary, the scaphoid is elongated, and extends, almost as much from the os lunare as from the radius, along the radial side of the carpus, to reach the trapezium and trapezoides; it is, as it were, interposed between the lunare of the proximal row and the trapezium and trapezoid of the distal row of the carpal bones. The similarity of its connections, therefore, in the carpus with those of the scaphoid in the tarsus (fig. 25, *sc.*)‡ is so close that the serial homology of the two bones is unmistakeable. The astragalus (*ib. a*), then, in the foot, repeats the os lunare (*l*) in the hand, but usurps the whole of the articular surface of the tibia, and presents a larger proportional size, especially in man, whose erect position required such exaggerated development of the astragalus, or homotype of the lunare. The prominent part of the calcaneum obviously repeats the prominent pisiforme (*p*), and the body of the calcaneum (*cl*) articulates with the fibula as the cuneiforme (*cu*) articulates with the ulna. The strain upon the homotype of the pisiforme to produce the required effect in raising the back-part of the foot with its superincumbent weight upon the resisting ends of the toes, required its firm coalescence with the homotype of the cuneiforme; in other words, the cunei-

* "L'extrémité supérieure du tibia est représentée par la moitié supérieure du cubitus, et la moitié inférieure du tibia par la moitié inférieure du radius; tandis que le péroné est représenté par la moitié supérieure du radius et par la moitié inférieure du cubitus."—*Anatomie Descriptive*, t. i. p. 315.

† Leçons d'Anat. Comp. t. i. 1836, p. 342.

‡ The carpal and tarsal bones are indicated diagrammatically in fig. 25; their ossification has not commenced at the period of the embryonic skeleton there represented.

forme and pisiforme of the carpus represent together the os calcis of the tarsus. With regard to the other bones there is no difficulty; the cuboid (*b*) supports the two ulnar digits, iv, v, of the foot, as the unciform bone (*u*) does those of the hand: the ecto-cuneiform supports the digitus medius, iii, of the foot as the os magnum (*m*) does that of the hand: the meso-cuneiform supporting the toe *ii* is the homotype of the trapezoid supporting the finger *ii*, and the ento-cuneiform (*ci*) is the homotype of the trapezium (*t*).

It is no unusual exception that of two essentially distinct bones in one segment being represented by a coalesced homotype—a single bone—in another segment, as in the explanation above given of the serial homology of the calcaneum. The scaphoides and astragalus in the tarsus of the lion are represented by the single scapho-lunar bone in the carpus. The scaphoid and a cuneiform bone in the tarsus of the sloth and megatherium are represented by the single scapho-trapezium in the carpus.

I have long entertained the opinion that an appreciation, vague and indistinct, perhaps, of certain serial homologies, may have been associated with, if it did not suggest the epithets "scapula of the head," "femur of the head," &c. applied to certain cranial bones by Oken and Spix.

To Cuvier this language seemed little better than unintelligible and mystical jargon, and he always alludes to it with ill-disguised contempt*. It has been commonly cited by those who have followed the great palæontologist in depreciating the cranio-vertebral theory, as a sufficient instance, needing no comment, of the extravagances essentially inherent in such attempts to recognise and explain the fundamental pattern to which the modifications of the cranial bones are subordinated. And it must be confessed that the expressions by which the philosophical anatomists of the school of Schelling have endeavoured to illustrate in the animal structures the transcendental idea of 'the repetition of the whole in every part,' have operated most disadvantageously and discouragingly to the progress of calm and dispassionate inductive inquiry into that higher law or condition upon which the power of determining the special homologies of the bones of the skeleton depends. Nevertheless the utterances of gifted spirits to whom the common intellectual storehouse is indebted for such original and suggestive generalizations as those contained in the "Program über die Bedeutung der Schädelknochen" are entitled to some, and we will hope to respectful consideration, even when they happen to be least intelligible or most counter to the conventional expressions of the current anatomical knowledge of the day; nor will the attempt to detect their latent meaning be wholly unproductive.

With regard, for example, to the term 'scapula capitis' applied by Oken to the tympanic bone in birds (fig. 23, 28), it is quite possible that some appreciation of its serial homology with ribs and other modifications of the pleurapophysial element, besides that exhibited by the blade-bone, may have lain at the bottom of the expression. And, we may ask, whether the error here be not rather in the mode of expressing the relationship than in the relationship itself? Had Oken, for example, said that the tympanic bone of the bird was a modified 'pleurapophysis,' or expressed by any other equivalent general term his idea of its standing in such general relation to its proper cranio-vertebral segment, his language would not only have been accurate, but might have been intel-

* "Quant à M. Oken—il déclare les pièces en question les parties écailleuses des temporaux, ou, selon son langage mystique, '*la fourchette du membre supérieur de la tête.*'"—Ossem. Foss. v. pt. ii. p. 75.—"Cet *humérus de la tête* de M. Oken devient pour M. Spix le *pubis* de cette même tête; ou, pour parler un langage intelligible, un des osselets de l'ouïe, savoir, le marteau."—"M. Spix croit aussi qu'il répond à la partie écailleuse du temporal, qu'il décore du titre d'*ilèon de la tête.*"—&c. *Ib.* pp. 85, 86.

ligible to Cuvier. When Oken called the 'tympanic' a 'cranial scapula' he unduly extended the meaning of the term 'scapula,' and converted it from a specific to a generic one. The tympanic is the homotype of the scapula, both being modified pleurapophyses, but each has an equal claim to its proper or specific name indicative of their respective modifications.

I am aware that Oken meant more than mere serial homology when he called the tympanic the 'blade-bone of the head': it is part of the phraseology of the hypothesis of the head being a repetition of the whole body, &c. But at the time when that anatomist wrote it was not known or suspected that the head already possessed the scapula, and that the modified pleurapophysis so called, actually appertained to a segment of the skull (fig. 5, 20, 21). In the terms '*femur capitis*,' '*tibia*,' '*fibula*,' '*pes capitis*,' applied by Oken to the parts of the teleologically compound mandibular ramus, and in those of '*ulna*' and '*manus capitis*,' applied to the distal segments (21, 22) of the maxillary arch, we have not only instances of the attempt to express general relations of repetition or homology by special terms, but these modes of expressing the serial homologies of nos. 20, 30, 32, and of 21 and 22, betrays the misappreciation of the general homologies of the locomotive extremities, and their relations to the vertebral arches supporting them.

To gain an insight into whatever proportion of truth may be involved in the ideas signified by the phrases above cited, it is necessary to determine the essential nature of the parts called 'femur,' 'tibia,' 'humerus,' 'ulna,' 'manus,' 'pes,' &c., or the general homology, in short, of locomotive members, and the attempt to master this problem has been not the least difficult part of the present inquiry. Cuvier has offered no opinion, nor does he appear to have ever troubled himself with the attempt to decipher the signification of the locomotive members of the vertebrate animals; *i. e.* of what parts of the primordial or pre-existing vertebrate model they are the modifications.

Oken's idea of the essential nature of the arms and legs is, that they are no other than 'liberated ribs': "Freye Bewegungsorgane können nichts anderes als frey gewordene Rippen seyn *."

Carus, in his ingenious endeavours to gain a view of the primary homologies of the locomotive members, sees in their several joints repetitions of vertebral bodies (*tertiar-wirbel*)—vertebræ of the third degree†—a result of an ultimate analysis of a skeleton pushed to the extent of the term 'vertebra' being made to signify little more than what an ordinary anatomist would call a 'bone.' But these transcendental analyses sublimate all differences, and definite knowledge of a part evaporates in such unwarrantable extension of the meaning of terms.

It has been, however, I trust, satisfactorily demonstrated that a vertebra is a natural group of bones, that it may be recognised as a primary division or segment of the endoskeleton, and that the parts of that group are definable and recognizable under all their teleological modifications, their essential relations and characters appearing through every adaptive mask.

According to the definition of which a vertebra has seemed to me to be susceptible, we recognise the centrum, the neural arch, the hæmal arch, and the appendages diverging or radiating from the hæmal arch. The centrum, though the basis, is not less a part of a vertebra than are the neurapophyses, hæmapophyses, pleurapophyses, &c.; and each of these parts is a different part from the other: to call all these parts 'vertebræ' is in effect to deny

* Lehrbuch der Natur Philosophie, p. 330, 8vo, 1843.
† Urtheilen des Knochen und Schalengerüstes, fol. 1828.

their differential and subordinate characters, and to voluntarily abdicate th power of appreciating and expressing them. The terms 'secondary' 'tertiary vertebræ' cannot, therefore, be correctly applied to the parts appendages of that natural segment of the endoskeleton to the whole which segment the term 'vertebra' ought to be restricted.

So likewise the term 'rib' may be given to each moiety of the hæmal ar of a vertebra; although I would confine it to the pleurapophyses when th present that long and slender form characteristic of the thoracic abdomi region, viz. that part of such modified hæmal or costal arch to which the te 'vertebral rib' is applied in comparative anatomy and the term 'pars os costæ' in anthropotomy: but, admitting the wider application of the te 'rib' to the whole hæmal arch under every modification, yet the bony verging and backward projecting appendage of such rib or arch is someth different from the part supporting it.

Arms and legs, therefore, are developments of costal appendages, but not ribs themselves liberated: although liberated ribs may perform an gous functions, as in the serpents and the *Draco volans*.

If then the arms or pectoral members be modified developments of diverging appendage of the scapulo-coracoid arch, and if this be the hæm arch of the occipital vertebra, it follows that the pectoral members parts of the head, and that the scapula, coracoid, humerus, radius and u carpals, metacarpals and phalanges, are essentially bones of the skull.

The transcendentalism, therefore, which requires for its illustration the maxillary arches be the arms and hands of the head, meets its most di refutation in the fact of the diverging appendages, properly called arms hands, belonging actually to one of the modified segments of which the h itself consists.

The head is, therefore, in no sense a summary or repetition of all the of the body: the skull is a province of the whole skeleton, consisting series of parts or segments essentially similar to those of which the res the skeleton is constituted.

Most of the phrases by which Spix attempted to systematize and carry the repetition-hypotheses of Schelling and Oken, as applied to the osteol of the vertebrate skull, may be similarly explained, and when well-winno some grains of truth may be recovered.

In denominating the palatine bone the 'hyoid bone of the face,' Spix deavours to express a relation of general homology by a term which sh be confined to the enunciation of a special homology: but he adds "co ossis hyoidei anteriori analogum," which shows an almost correct appr ation of the serial homology of the palatine bone. It answers, however the maxillary arch to the stylo-hyal or proximal element of the hyoid arch, not to the cerato-hyal or hæmapophysial element; and it needs on recognise the palatine as the 'pleurapophysis' of its vertebral segment appreciate all its true serial homologies. It might as well have been called 'tympanic pedicle of the face,' the 'styloid process,' the 'scapula,' the 'verte rib,' or the 'ilium—of the face', according to Oken's and Spix's faulty me of expressing serial homological relations, since it holds in its vertebral seg the same place which each of the above-named bones respectively does i segment.

So also, with regard to the term 'os faciei iliacum' applied by Spix to mastoid (s), the error lies not only in the application of a special term to press a general homological relation, but in the supposed serial homolog expressed. Had Spix detected, in a cranial vertebra, the precise elem answering to that called 'iliac bone' in a post-abdominal vertebra, ye

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would have been more proper to have signified such serial homologs by giving the general term applicable to such parts, as abstract vertebral elements.

The fact is, however, that the mastoid (s) is the parapophysis of its vertebra, whilst the ilium is a portion of the pleurapophysis of its vertebra; and the mastoid is serially homologous with the transverse process (parapophysis) of a sacral vertebra (fig. 27, *p*), not with the pleurapophysis or 'ilium'; it is not, therefore, a repetition of the ilium in the skull. The true expression of the ideas which suggested the terms 'ilium of the head,' 'scapula of the head,' &c., will be found in the true enunciation of the serial homologies of the vertebrate skeleton.

It finally remains for inquiry, admitting the explanation of the endoskeletal archetype given in this Report to be the true one, whether such is the ultimate attainable generalization, or whether we may not also gain an insight into the nature of the force by which all the modifications of the vertebrate skeleton, even those subservient to the majesty of man himself, are still subordinated to a common type.

We perceive in the fact of the endoskeleton consisting of a succession of segments similarly composed,—in the very power, in short, of enunciating special, general and serial homologies,—an illustration of that law of vegetative or irrelative repetition which is so much more conspicuously manifested by the segments of the exoskeleton of the invertebrata, as, for example, in the rings of the centipede and worm, and in the more multiplied parts of the skeletons of the echinoderms.

The repetition of similar segments in a vertebral column, and of similar elements in a vertebral segment, is analogous to the repetition of similar crystals as the result of polarizing force in the growth of an inorganic body.

Not only does the principle of vegetative repetition prevail more and more as we descend in the scale of animal life, but the forms of the repeated parts of the skeleton approach more and more to geometrical figures; as we see, for example, in the external skeletons of the echini and star-fishes: nay, the calcifying salt actually assumes in such low-organized skeletons the very crystalline figures which characterize it when deposited, and subject to the general polarizing force, out of the organized body. Here, therefore, we have direct proof of the concurrence of such general and all-pervading polarizing force with the adaptive or special organizing force in the development of an animal body.

The marvellous phænomena of this development have, hitherto, been explained by two hypotheses or forms of expression, as the result, viz. of 'vital properties' either peculiar to living matter or common to all, but latent in dead, matter; or, as due to the operation of one or more 'vital principles,' vital forces, dynamies or faculties, answering to the ἰδέαι of Plato, deemed by that philosopher to be superadded to matter and mind, and which he defined as a sort of models, or moulds in which matter is cast, and which regularly produce the same number and diversity of species*.

Now besides the *ἰδέα*, organizing principle, vital property, or force, which produces the diversity of form belonging to living bodies of the same materials, which diversity cannot be explained by any known properties of matter, there appears also to be in counter-operation during the building up of such bodies the polarizing force pervading all space, and to the operation of which force, or mode of force, the similarity of forms, the repetition of parts, the signs of the unity of organization may be mainly ascribed.

The platonic *ἰδέα* or specific organizing principle or force would seem to

* See Barclay, Life and Organization, 8vo, 1822.

be in antagonism with the general polarizing force, and to subdue and mould it in subserviency to the exigences of the resulting specific form.

The extent to which the operation of the polarizing or vegetative-repetition-force is so subdued in the organization of a specific animal form becomes the index of the grade of such species, and is directly as its ascent in the scale of being. The lineaments of the common archetype are obscured in the same degree: but even in man, where the specific organizing force has exerted its highest power in controlling the tendency to type and in modifying each part in adaptive subserviency to, or combination of power with, another part, the extent to which the vegetative repetition of segments and the archetypal features are traceable indicates the degree in which the general polarizing force may have operated in the arrangement of the parts of the developing frame: and it is not without interest or devoid of significance that such evidence should be mainly manifested in the system of organs in whose tissue the inorganic earthy salts most predominate.

On Anemometry. *By* JOHN PHILLIPS, *F.R.S., F.G.S.*

ANEMOMETRY, or the registration of wind, is a process of recording certain effects of the (horizontal) pressure or movement of the atmosphere. According to the kind of effect which is subjected to observation, and to the process of measuring, weighing or counting which is adopted, the anemometrical instruments vary, and it is required to determine the forms of these instruments which are best adapted for accurate meteorological inquiries. Correct anemometers may be applied with advantage as auxiliaries in a variety of important problems not meteorological, but they are of primary importance in meteorology, and derive their value in other branches of knowledge from their proved adaptation to this.

A complete anemometrical register should give on a scale of time the direction of the wind, and its pressure or velocity in a continuous series, or at very frequent intervals, for days, weeks, months or years. We may for particular inquiries be desirous of learning the total space traversed by the aërial movement, or be satisfied with knowing the maxima and minima of pressure, in a given period of time, or in other ways simplify the problem, which in its general form cannot be solved without adding a clock or other register of time to the apparatus for measuring wind.

Mechanical Effects of the Movement of the Atmosphere.

The (horizontal) movement of the air over any given point on the earth's surface, one of the most important desiderata in meteorology, can only be observed *directly* in the phænomena of the clouds. The velocity of these light bodies may be measured trigonometrically, by their change of position, or when the sun shines, by observing the progress of their shadows on the ground. But these are rather *experiments* than *observations*, and when we attempt by instrumental means to register the *velocity of the wind*, some considerable difficulties at once appear. The air moves because it is *pressed*: machines to be influenced by wind must be made to receive and yield to its pressure. If this pressure be received on a machine so contrived that it has a resisting power, which rises with the increase of pressure till equilibrium is gained, the displacement of the spring, the elongation of the lever, the augmentation of the weight, &c. may be taken as proportioned to the

PRESSURE. Many such instruments have been invented, the most famous being M. Osler's anemometer, first erected at Birmingham.

But if the pressure (P) be received on an instrumental contrivance, which (its inertia being overcome) is set into a continuous motion (as the various sorts of windmills), the rate of this motion goes on increasing till the resistance which the motion generates balances the wind-pressure on the sails. This resistance consists of two parts, one caused by the displacement of the air in the path of revolution of the sails, and consequently proportioned to the square of the velocity of revolution (or to v'^2); the other caused by the ordinary friction of machinery, which being a uniformly retarding force (b), destroys the power P exerted on the machine a quantity proportioned to the space moved over*, and consequently to v'. P then is prop. to $a v'^2 + b v'$, the coefficients a and b requiring to be separately determined for each instrument.

If we conceive friction to be very small, so that the second term almost vanishes, the velocity of revolution becomes nearly proportioned to V, the velocity of the wind; but if friction be very large, the velocity of revolution of the machine becomes nearly proportioned to P or V^2. The former is the case on a windmill in heavy wind-pressures; the latter of the same machine when the wind-pressure is light†.

Hence all machines of this kind have a rate of revolution proportional to the movement of the air, retarded by quantities which are proportioned to something else. The smaller we can make this retardation, the nearer to perfection is the instrument. Such an instrument is Whewell's anemometer.

Whewell's Anemometer.—Assuming in respect of this instrument that its general action is like that of a windmill, we see with low velocities of wind, the term $b v'$ is not only greater in proportion to $a v'^2$ than with high velocities, but may acquire a higher numerical value than it.

Coulomb found with a windmill (the load being constant), the following proportions of wind's velocity and revolutions of sail:—

Wind Vel.	Revolutions.
V.	v'.
7·0	3·0
12·5	7·5
20·0	13·0
28·0	22·0

We may with these data compare the following calculation:—

Wind Vel. V.	Revolutions. v'.	Calculation. $a v'^2 + b v' =$	Sum. $= v^2$.	V Calculated.	Difference.
7·0	3·0	9·0 + 44·3	53·3	7·30	+0·30
12·5	7·5	55·3 + 100·6	165·9	12·88	+0·38
20·0	13·0	169·0 + 191·8	360·8	18·99	−1·01
28·0	22·0	484·0 + 324·6	808·6	28·43	+0·43

* This is not strictly the case with varying pressures of wind, if these act unequally on the bearings of the axles.

† Mr. Harris's experiments with Whewell's anemometer (Reports of the British Association, 1844, p. 245) confirm this view. He had previously observed (Reports of the Association, 1842, p. 33) in one limited set of experiments with low velocities of wind, the space described by the pencil to be proportional to the square of the velocity of the wind. But in a larger series of trials, in strong and steady breezes, the spaces passed over by the pencil came nearer the simple ratio of the wind's velocity. In strong winds the ratio between the revolutions of the fly and the velocity of the wind is [nearly] constant.

Lind's anemometer corresponds to the space from 0·0 to 0·10 inch, and to a velocity of from 0 to 15 feet per second, that is to say, 0 to 10 miles per hour*.

Except the instrument be very carefully constructed, this degree of accuracy is unattainable, and pressures less than $\frac{1}{4}$lb. per foot, and velocities of several miles per hour, may not be recorded at all. One of the most interesting of the powers connected with the use of this instrument has been already noticed,—the power of studying the momentary phases of air-movement at the observatory. This is peculiar to the principle of Mr. Osler's invention; another result of great importance has been derived from the study of its tracings. The force of the wind for every hour of the day and night has been determined not only for the whole air-movement, but for each direction of wind, and in each season of the year. Mr. Osler's conclusions on this subject, supported by Harris, Brewster and Sabine, go directly to determine a law of the wind's daily pressure and to connect it with the progress of diurnal heat. In fact the curves of daily wind-force and of daily mean temperature are almost identical, as may be seen in Col. Sabine's Observations on the Meteorology of Toronto.

The same registration gives data for investigating what may be called curves of storm pressure, the law according to which wind-pressure rises to a maximum and sinks to a minimum, a subject of great interest and importance. From some data which may be found in Mr. Osler's Report, in the volume of the Association for 1840, I have obtained the following Table of pressures during a strong wind of 96 hours' duration.

* It may be useful to give here Smeaton's Table of Wind Velocity in relation to Pressure in lbs. (Phil. Trans. 1759.)

Velocity of Wind.		Pressure on one square foot in lbs. avoirdupois.	Character of the wind.
Miles per Hour.	Feet per Second.		
1	1·47	·005	Hardly perceptible.
2	2·93	·020	Just perceptible.
3	4·40	·044	
4	5·87	·079	Gentle pleasant wind.
5	7·33	·123	
10	14·67	·492	Pleasant brisk gale.
15	22·00	1·107	
20	29·34	1·968	Very brisk.
25	36·67	3·075	
30	44·01	4·429	High wind.
35	51·34	6·027	
40	58·68	7·873	Very high.
45	66·01	9·963	
50	73·35	12·300	Storm or tempest.
60	88·02	17·715	Great storm.
80	117·36	31·490	Hurricane.
100	146·70	49·200	Destructive hurricane.
913·6	1340*	One atmosph.	

$\sqrt{h}$ atmosphere in feet $\times 8\frac{1}{4}\sqrt{2}$ = feet per second.

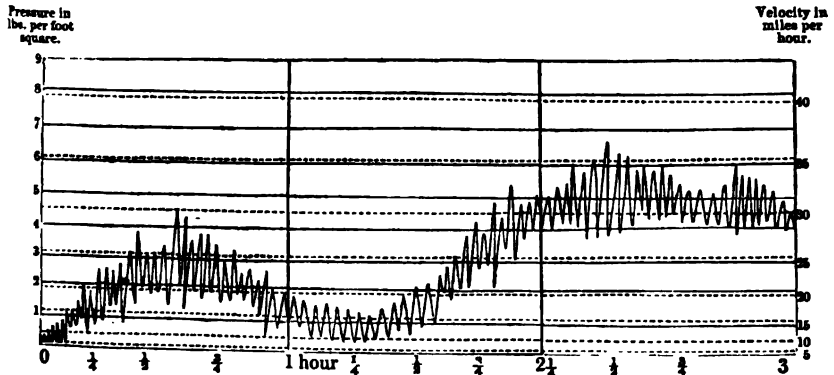
Table of Mean and Minimum and Maximum Wind-pressures during 96 hours.

	Maximum.	Minimum.	Mean.
First twelve hours	2·5	0·5	1·5 lb.
Second twelve hours	2·0	1·0	1·5416+
Third twelve hours	3·5	2·0	2·5
Fourth twelve hours	4·5	3·0	3·5416+
Fifth twelve hours	4·5	2·5	3·2916+
Sixth twelve hours	2·5	2·0	2·125
Seventh twelve hours	2·0	1·0	1·54
Eighth twelve hours	2·0	0·5	1·0

The regularity of the results is conspicuous when represented by curves. The central ordinate of pressure is seen to occur two hours before the middle hour of time. It occurs in a lull of the wind.

It is much to be wished that the numerous observations which have been made with Osler's anemometer under the direction of the Association, should be reduced and tabulated so as to determine from them the *annual air-movements* over the place of observation, for comparison with the result given by Mr. Harris at Plymouth. The registers for Inverness, Edinburgh, Dublin, Birmingham, Greenwich and Plymouth, thus brought together, would afford a valuable basis for reasoning on the leading vicissitudes of British climate. This will probably be included in the reductions on which Mr. Harris is now engaged.

It is neither an obvious nor an easy thing to obtain *correctly* the mean velocity of air-movement, or the total horizontal transference of the air in a given period, from the register of wind-pressure. The *momentary* velocity is a constant function (the square root) of the momentary pressure; but the *mean* velocity is not a constant function of the mean pressure; the *total* air-movement is not a constant function of the sum of the pressures. The larger the range of these pressures, the more variable is the relation of the mean velocity and the mean pressure; the duration of the several values of pressure influences the calculation of the total air-movement, so that to obtain it even approximately from a register of momentary pressures a great number of these must be separately valued and reduced to velocity, and this is a great arithmetical labour. It might be diminished if we could assume as sufficiently known, the *law* of the variation of the pressure, from 0 to the maximum, and calculate corrections in conformity with the successive swellings and subsidings of the wind; but this would still leave the result unsatisfactory.



A mechanical process may be substituted with evident advantage. If r

the register paper now ruled for a scale of momentary pressure, we rule *another scale*, that of momentary velocity, or *copy* the register on a paper prepared with such a scale, the ordinates of velocity may be *measured off* with nearly as much accuracy as those of pressure, and the mean velocity and total air-movement be approximately obtained with great facility. It is obvious that the paper in Mr. Osler's apparatus may be ruled, as in the specimen, p. 345, both for velocity and pressure, with very little additional expense.

The pressure lines may be continuous, the velocity lines dotted. Such a table shows how imperfectly the registration of wind-*pressure* to one pound, or even one-tenth of a pound per square foot, satisfies the question of the *velocity* of the wind. In many cases winds of several miles an hour have been left entirely unnoticed.

Lind's Anemometer.—In Lind's anemometer, the pressure of wind is balanced by the weight of a column of water, + the force due to the friction of its movement. Owing to the facility of liquid movements, this instrument, if made with a siphon of large diameter, is very quick in its indications, and prettily exhibits what Mr. Osler's pencils record, the continual fluctuations of the wind. Pressures which move the water to a difference of level of less than one-twentieth of an inch, can scarcely be noted accurately, but may be estimated to one-fortieth or one-fiftieth. This gives as the limit of wind-velocity really measurable five or seven miles an hour.

Lind's anemometer may be rendered self-registering, but not without some sacrifice of its quickness and accuracy *.

It is possible to arrange apparatus which shall allow of the *flowing of a* liquid under the pressure of the atmosphere with the velocity due to that pressure; it is also possible so to regulate the *direction* of this flowing that the direction shall be known of the wind to which the efflux is due; and in other ways the apparatus may be varied; but it does not appear that by these processes any real advantage can be gained over the instruments of Whewell and Osler, when these are properly attended to. I proceed therefore to another view of the subject.

Molecular Effects of the Movement of the Atmosphere.

The class of phænomena to which attention is now requested depends on the molecular condition of the air, and on its rate of movement; if it can

* Table for Lind's Anemometer.

Difference level in inches.	lbs. Pressure.	Vel. in miles per hour.
0·25	1·3	18·0
0·5	2·6	25·6
1·0	5·2	36·0
2·0	10·4	50·8
3·0	15·6	62·0
4·0	20·8	76·0
5·0	26·0	80·4
6·0	31·3	88·0
7·0	36·5	95·2
8·0	41·7	101·6
9·0	46·9	108·0
10·0	52·1	113·6
11·0	57·3	119·2
12·0	62·5	124·0

be made the basis of wind-registration, there will be no mechanism required for recording the measures of air-movement or pressure, and the scale of results will increase in accuracy as the wind-force grows less, and may be in this direction more and more trusted as we approach to zero; a circumstance which would confer upon this mode of anemometry a peculiar value, and render it almost a necessary complement to the mechanical processes now in use, for these take but little notice of very light winds, which yet it is of much importance to record.

One of these joint effects of the molecular constitution of the air, combined with its rate of movement, is seen in the rapidity with which objects exposed to wind acquire the temperature of the atmosphere.

If a thermometer whose temperature differs from that of the atmosphere by m degrees be exposed *in the open air*, it instantly begins to undergo change of temperature, and loses or gains heat continually until it has become sensibly of the same temperature as the surrounding medium. This effect, a mixed result of radiation and conduction of heat, is *in the open air* very nearly in simple proportion to m; but in *closed vessels*, where conduction is impeded and radiation influential, the changing temperature of the surrounding bodies complicates the experiment, and the wet thermometer does not in this case lose or gain heat in the same simple proportion to m.

Exposure of the thermometer to a current of wind accelerates the process by which its temperature is made sensibly equal to that of the surrounding medium, and thus by careful experiments the momentary velocity of the current may be estimated, as Sir John Leslie has proposed*.

If we maintain a continual moisture on the bulb of the thermometer, a new element of change of temperature is introduced, the force of vaporization, the effect of which is finally to reduce the thermometer to the temperature of evaporation, where it remains.

If we commence the experiment with the temperature of the wet bulb raised by the quantity m above that of the surrounding atmosphere (t), it will sink under the operation of two forces, the cooling power of air, proportioned to m, and the force of vaporization. (The movement of the air is not now considered.) By the *sum* of these forces it approximates to t, at which point m being $=0$, the cooling power of the air ceases. By the force of vaporization it is depressed below this point to t', but between t and t' the air exerts a heating power proportioned to m. The rate of cooling in air of a wet-bulb thermometer is thus found to be complicated with two quite distinct functions, at every point but one, viz. at the temperature t of the atmosphere; at this point it depends solely on the force of vaporization, modified by the movement of the air. If then we perform a series of experiments on the rate of cooling of a wet-bulb thermometer exposed in the open air, from $t+\frac{1}{2}^\circ$ to $t-\frac{1}{2}^\circ$, under the influence of winds of very unequal velocity, and under the influences of very unequal degrees of dampness in the air, we shall be able to distinguish the effects of these influences, and assign to each its proper functional expression. But if one of these can be determined theoretically, fewer experiments will be required. It appears that the cooling influence of evaporation at different temperatures and in different hygrometrical states of the atmosphere can be thus determined.

The *rate of evaporation of water* in the atmosphere depends upon the *force of aqueous vapour at that temperature, diminished by the force of the aqueous vapour actually present in the atmosphere.* Thus if f' represent the force of vapour at the temperature of evaporation, and f'' the force of vapour at the temperature of the dew-point, $f'-f''$ is the unbalanced and active force

* Professor Forbes in Reports of the British Association for 1832.

which determines the *rate* of evaporation into the open air. Now by Dr. Apjohn's researches $f'-f''$ is exactly proportional to $\frac{d}{88} \times \frac{h}{30}$, where d is the difference in degrees between the temperature of the air and the temperature of evaporation, and h the barometric pressure. Water undergoing evaporation takes up for each unit of weight a certain measure of heat from the substances in contact; its cooling effect on them is therefore proportioned to the quantity of water evaporated in a given time, which again is proportional to the force $f'-f''$, that is, to $\frac{d}{88} \times \frac{h}{30}$.

A convenient mode of experiment to obtain separately the cooling power of evaporation from that of air currents and radiation, is to note the times of cooling of one thermometer first dry and then wet, other circumstances being similar, as in the following experiment, made in the calm air of a large room (air 55°, evaporation 47·8, dew-point 38·6).

Temp. of Thermometer.	Time of cooling 5° in seconds.	
	dry.	wet.
105	0	0
100	45	18
95	52	21
90	60	23
85	70	29
80	85	36
75	102	42
70	125	54
65	168	70
60	257	93
55	.....	137
50	.....	253

The reciprocals of these times $(\frac{10,000}{T})$ correspond to the cooling powers exerted on the two instruments and appear in the following table (column A and B). The difference between them obviously corresponds to the cooling power of evaporation exerted on the wet bulb (column C). Column D contains the numerical values of the forces of evaporation due to the successive temperatures of the bulb in the existing state of the air; and column E a series of numbers proportioned to these, and representing the successive cooling powers as they ought to be found experimentally if the theory already advanced be true. F shows the difference between theory and experiment.

Mean Temp.	A.	B.	C.	D.	E.	F.
	dry.	wet.				
102·5	222	555	333	1·758	352	+19
97·5	192	476	284	1·458	292	+ 8
92·5	166	435	269	1·208	242	−28
87·5	143	344	201	1·014	203	+ 2
82·5	117	279	162	·831	166	+ 4
77·5	98	237	139	·673	135	− 4
70·5	80	185	105	·535	107	+ 2
67·5	59	143	84	·418	84	0
62·5	38	107	69	·316	63	− 6
57·5	20	73	53	·229	46	− 7
52·5	.....	40	.....	·155	31	
47·5	.....	.....	.....	·091	18	
38·6	.....	.....	.....	·000	0	

The truth of the theory may therefore be regarded as established, the small differences being quite unimportant.

On regarding attentively the columns A, B, it will be seen that the progression of each is *nearly* similar, from which it follows that C, their difference—representing their cooling power of evaporation—contains a series of numbers nearly proportioned to B. Ranging these columns side by side, and reducing to the same mean values, we have

B.	C.	E.
323	333	344
277	284	285
253	269	236
200	201	198
162	162	162
138	139	132
107	105	105
83	84	82
62	69	61
43	53	45

From which it follows, that for temperatures of the wet bulb above that of the atmosphere, we may disregard the correction in column A, and take the *whole cooling effect* of air and vapour, as proportioned to the vaporizing force. The problem is thus simplified for practical use.

To judge if the same rule applies when the temperature of the wet bulb is below that of the atmosphere, the following sets of experiments were made in the open air, with variable differences between the temperature of the air and that of the wet bulb (air 75°, evap. 63°):—

Temperature of air above that of wet bulb.	I. Thermometer at rest.	II. Thermometer swung slowly.	III. Thermometer swung faster.	IV. Mean of observed times.
10″	17″	13″	12″	14·0″
9	18	13	11	14·0
8	19	14	15	16·0
7	20	20	16	18·6
6	26	24	17	22·3
5	30	26	24	26·6

The numbers in columns I. II. III. IV. represent the seconds of time in cooling 1°of the wet thermometer.

With the mean of the times we may compare a series of numbers proportioned to the vaporizing force due to the temperatures, in the given condition of air, as under:—

Temperature of air above that of wet bulb.	Mean of observed times.	Calculated times.
10	14·0	13·0
9	14·0	14·4
8	16·0	16·3
7	18·6	18·6
6	22·3	21·6
5	26·6	26·1

From which it appears that the rate of cooling of the wet bulb is still nearly proportional to the force of vaporization, until the temperature of the wet bulb deviates much from that of the atmosphere.

For determining the influence of the rate of air-movement on the rate of cooling of the wet bulb, several processes have been employed, both in the open air and in the house.

1. In the first place, choosing a day when the air was considered nearly calm, (*i. e.* moving so gently that only leaves with very flexible petioles were swayed by it,) the wet bulb was first suspended at *rest* in this gentle current (A); secondly, it was *carried* across it (B) at the rate of 2·75 miles an hour; thirdly, it was *swung* across it at the rate of 6·18 miles an hour (C). The effects are recorded in the table below.

Experiment of 22nd Aug. 1846. Temperature of air 75°, of evaporation 63° ($d=12$).

	A.	B.	C.
Time of cooling 1°	16·	12·	9·

Reciprocals of these numbers, which represent the cooling powers of the air in the several conditions, appear below :—

A.	B.	C.
625	833	1111;

and are obviously not in simple proportion to the velocity of the air-movement in the several cases. If we suppose the so-called 'calm' air to move two miles an hour (which the movement of smoke at the time seemed to indicate), the velocities, obtained by calculating the diagonals of the air-movements combined with the thermometer-movements, would be as under :—

A.	B.	C.
2·00	3·40	6·48,

and their square roots, viz.—

1·41	1·84	2·55

approach nearly to the ratio of the cooling powers.

2. Experiments of this kind however being unsusceptible of much precision, recourse was had to railway movement in a 'calm' day. Temperature of air 70°, of evaporation 64° ($d=6$). Time of cooling 1°, at 3 inches from the carriage window, 14″; at 18 inches, 10″; at 24 inches, 9″.

Again, on another occasion, temperature of air 69°·5, of evaporation 64° ($d=5·5$). Time of cooling 1°, at 20 inches distance from the window, 10″.

In each of these cases the real velocity of the train was believed to be about 36 miles an hour.

These experiments are sufficiently in accordance with those already discussed to allow of our applying the formula $\frac{C}{d\,T} = \sqrt{V}$ to all; where T is the observed time of cooling 1° and C a constant peculiar to the instrument. By taking C = 300, and employing this value for the several experiments, the estimated and calculated results appear thus :—

	Estimated velocity in miles.	Calculated velocity in miles.
'Calm' air	2·00	2·44
Thermometer carried ...	3·40	4·31
Thermometer swung ...	6·48	7·71
Railway movement.....	36·00	30·86
Railway movement.....	36·00	29·75

As all these experiments are complicated with the uncertain and variable influence of what is called 'calm' air, their accordance with one general formula appears qu[illegible]s could be expected. The *drag* of air, which the unequal ra[illegible]ifferent distances from the carriage indicate,

may perhaps not be wholly eliminated at even 20 or 24 inches distance. Perhaps no better mode of experiment on this peculiar transportation of the atmosphere by railway trains could be devised than the trial of its cooling power. In the first of the above experiments the air-displacement appeared to be about 13 miles an hour at 3 inches from the carriage; about 24 miles at 18 inches, and 30 miles at 24 inches.

The result now arrived at must, however, be regarded as only a first approximation, and requires to be tested and corrected by more rigorous processes. For this purpose the cooling of the wet bulb has been observed when carried round by a lathe movement, and when subject to the vibrations of a pendulum. The results are yet incomplete, but may be offered for the consideration of the Association on a future occasion.

Report on the Crystalline Slags. *By* JOHN PERCY, *M.D.*

We have pleasure in now presenting to the Association the results of our investigation of the crystalline slags. It is obvious that such an investigation must be limited by the opportunity of obtaining specimens, which require to be diligently sought for at the various metallurgical works; and that, consequently, it is impossible for us at present to offer anything like a complete report upon this interesting subject. We have however been fortunate in procuring already an extensive series of beautifully crystallized slags, several of which we have not yet had time to examine. We are especially indebted to Mr. John Dawes, of West Bromwich, and to Messrs. Blackwell and Twamley, of Dudley, for many valuable contributions. In the present Report we have confined our attention to the slags produced in the smelting and manufacture of iron. We shall adopt the following arrangement:—

1. The crystallographic and mineralogical description by Professor Miller.
2. The analysis*.
3. Special remarks.

The first series is composed of six specimens. Nos. 1 and 2 were obtained from hot-blast furnaces in the vicinity of Dudley; Nos. 3 and 4 from Messrs. Blackwell's hot-blast furnaces at Russell's-hall, near Dudley; No. 4 from one of Mr. Philip Williams's cold-blast furnaces, at the Wednesbury Oak Works, near Tipton; No. 6 was brought by Mr. Samuel Blackwell from a hot-blast furnace named La Providence, at Marchienne, Charleroi, Belgium. No. 3 was produced when the furnace was considered to be working unsatisfactorily, from some interruption to the free course of the blast.

The crystals of the slag No. 3 are square prisms, terminated by planes perpendicular to the axis of the prism. Many of the prisms have their angles truncated by planes, making equal angles with the adjacent faces of the prism.

$$\text{Hardness} = 6.\ \text{At } 19°1\ \frac{\text{specific gravity of slag}}{\text{specific gravity of water}} = 2{\cdot}9242.$$

The crystals of slag No. 4 are square prisms, having the angles truncated like No. 3.

$$\text{Hardness} = 5{\cdot}5.\ \text{At } 18°{\cdot}2\ \text{C}\ \frac{\text{specific gravity of slag}}{\text{specific gravity of water}} = 2{\cdot}9187.$$

* I am happy to state that I have had the assistance of my friend Mr. David Forbes, brother of Professor Edward Forbes. To the analyses made by myself I shall append my own initials, and to those made by Mr. Forbes the initials of that gentleman.

The crystals of No. 5 are square prisms, having the angles truncated like No. 3. Hardness = 5·7.

No. 1. Square prisms like No. 3.

$$\text{Hardness} = 6.\ \text{At } 19°{\cdot}2\ \text{C}\ \frac{\text{specific gravity of slag}}{\text{specific gravity of water}} = 2{\cdot}9052.$$

No. 2. Square prisms like No. 3.

$$\text{Hardness} = 6.\ \text{At } 19°{\cdot}2\ \text{C}\ \frac{\text{specific gravity of slag}}{\text{specific gravity of water}} = 2{\cdot}9152.$$

Analysis.—The slags composing the first series were found to contain silica, alumina, lime, magnesia, protoxides of manganese and iron, potass in small quantity, and sulphur as sulphuret. Phosphoric acid was also found in some of them. They are readily decomposed by digestion with dilute hydrochloric acid. The following method of analysis was adopted.

Method of Analysis.—1. The fine powder obtained by trituration in an agate mortar was digested with dilute hydrochloric acid. The whole was evaporated to dryness. The dry mass was treated with hydrochloric acid, and left for a few hours. Nitric acid was added sometimes before and sometimes after evaporation to peroxidize the iron. The silica separated by filtration was washed with boiling water until nitrate of silver ceased to produce the slightest turbidity, dried, incinerated at a bright red heat, cooled under a glass shade containing sulphuric acid, and then weighed.

2. To the acid solution was added a slight excess of ammonia. Filtration was conducted as rapidly as possible, the funnel being covered with a glass plate.

3. The precipitate (2) was boiled with potass. The solution was treated with an excess of hydrochloric acid, and the alumina then precipitated by carbonate of ammonia.

4. The insoluble residue (3) was dissolved in hydrochloric acid, and the iron was precipitated by succinate of soda or ammonia with the usual precautions.

5. The lime was precipitated by oxalate of ammonia from solution (2), after treatment by ammonia. The precipitate, which consisted of oxalate of lime mixed with oxalate of manganese, was incinerated at a bright red heat, and then digested with dilute acetic acid, which dissolved the lime and left the brown oxide of manganese. A slight excess of sulphuric acid was added to the solution of acetate of lime; the whole was evaporated to dryness, and heated to redness; from the sulphate of lime thus obtained the lime was calculated.

6. The solution (4), after separation of the iron, was added to solution (5) after separation of the lime. The manganese was precipitated by hydrosulphate of ammonia in a close vessel, and in every instance at least twelve hours were allowed for precipitation. The sulphuret of manganese was dissolved in hydrochloric acid, and precipitated as carbonate by carbonate of potass. The carbonate of manganese was incinerated at a bright red heat for a considerable time. The oxide of manganese thus produced was estimated as $MnO + Mn^2O^3$.

7. The solution (6), after precipitation of the manganese, was digested with excess of hydrochloric acid until the sulphur separated by decomposition of the excess of hydrosulphate of ammonia had completely separated. The magnesia was precipitated by phosphate of soda and excess of ammonia. Generally twenty-four or forty hours were allowed for complete precipitation. The precipitate was washed with ammonia-water until no sensible residue was left by eva- -late of glass. When dry, generally as much of the magne- 'e was detached from the filter, and

slowly heated to redness; the filter, with what adhered to it, was then introduced into the crucible and incinerated as usual.

8. To determine the potass, the slag was digested as usual in hydrochloric acid, the iron was peroxidized by nitric acid, and the solution was then treated with excess of carbonate of ammonia. The filtrate was evaporated to dryness, and the ammoniacal salts were expelled by heat. The residue was treated with boiling water, and the solution filtered from the brownish residue. The filtrate was evaporated to dryness after the addition of excess of sulphuric acid. The residue was dissolved in water, acetate of baryta was added in excess, the sulphate of baryta was separated with the usual precautions by filtration; the filtrate was evaporated to dryness, and afterwards heated to redness. The solution contained the potass as carbonate; hydrochloric acid was added, and from the amount of chloride obtained by evaporation and heating to low redness, the potass was estimated. Berzelius's method of separating potass from magnesia by oxide of mercury was also occasionally resorted to.

9. The sulphur was determined either by oxidizing with strong nitrous acid, or by fusing with nitrate of potass and a mixture of carbonate of potass and soda. Chloride of barium was added to the acid solution. From the sulphate of baryta produced the sulphur was estimated.

10. The method resorted to for the detection of phosphoric acid will be described in each case.

The actual quantities of the substances found by analysis will always be given, in order that the calculations may be corrected in the event of any errors in the received atomic weights being corrected by future observers. The calculations have been made from the tables in the French translation of Rose's work by Peligot (Paris, 1843).

1. Analysis. By J. P.

1. Weight of slag employed 27·57 grains, after having been gently heated over a spirit-lamp.
2. Silica 10·49.
3. Alumina 3·89.
4. Sulphate of lime 24·35.
5. Phosphate of magnesia ($2MgO, P^2O^5$) 5·74.
6. Oxide of manganese ($MnO + Mn^3O^4$) 0·12.
7. Sesquioxide of iron 0·39.
8. Potass. Weight of slag employed 50·47 grains. Chloride of potassium 1·48. A minute quantity of precipitate was produced by the addition of antimoniate of potass to the solution. The quantity of chlorine was determined by nitrate of silver. The chloride of silver obtained weighed 2·814 grains, which correspond to 0·694 of chlorine. 1·48 of chloride of potassium by the tables, contains 0·702 of chlorine. Difference 0·702—0·694=0·008. The chloride may therefore be estimated as nearly pure chloride of potassium.
9. Sulphur. Hydrosulphuric acid was liberated by the action of hydrochloric acid. Weight of slag 22·68. The nitrous acid process was employed. The sulphate of baryta weighed 0·59. It was ascertained that the slag did not contain sulphuric acid. The sulphur is admitted to exist as sulphuret of calcium.
10. Phosphoric acid was not detected. Weight of the slag employed 51·38 grains. It was digested with hydrochloric acid, and the silica separated as usual. The precipitate obtained by the addition of ammonia in slight excess was dissolved by hydrochloric acid; tartaric acid was adde

and then chloride of magnesium and excess of ammonia; no trace of the characteristic precipitate of phosphate of magnesia and ammonia appeared after several days.

Analysis tabulated.			Oxygen.
Silica	38·05		19·76
Alumina	14·11		6·59
Lime	35·70	10·03	13·35
Magnesia	7·61	2·94	
Protoxide of manganese	0·40	0·09	
Protoxide of iron	1·27	0·29	
Potass	1·85		0·31
Sulphuret of calcium	0·82		
Error of loss	0·19		
	100·00		

2. Analysis. By J. P.

1. Weight of slag employed 25·41 grains, after having been gently heated over a spirit-lamp; the odour of free sulphur was distinctly remarked.
2. Silica 9·85
3. Alumina 3·68.
4. Sulphate of lime 22·04.
5. Phosphate of magnesia 4·76.
6. Oxide of manganese 0·07.
7. Sesquioxide of iron 0·34.
8. Potass. Weight of slag employed 46·93. Chloride of potassium 0·82. By treatment with nitrate of silver 1·51 grain of chloride of silver was obtained, which corresponds to 0·372 of chlorine. 0·82 of chloride of potassium contains 0·389 of chlorine.
9. Sulphur. Hydrosulphuric acid was evolved by the action of hydrochloric acid. Weight of slag 20·06. The nitrous acid process was employed. The sulphate of baryta weighed 0·63.
10. Phosphoric acid was not sought for.

Analysis tabulated.			Oxygen.
Silica	38·76		20·13
Alumina	14·48		6·76
Lime	35·68	10·02	12·89
Magnesia	6·84	2·55	
Protoxide of manganese	0·23	0·05	
Protoxide of iron	1·18	0·27	
Potass	1·11		0·19
Sulphuret of calcium	0·98		
Error of loss	0·74		
	100·00		

3. Analysis. By J. P.

1. Weight of the slag employed 25·27, after having been gently heated over a spirit-lamp.
2. Silica 9·51.
3. Alumina 3·23.
4. Sulphate of lime 20·68.
5. Phosphate of magnesia 4·58.
6. Oxide of manganese 0·72.
7. Sesquioxide of iron 1·18.

8. Potass. Weight of slag 50·47. Chloride of potassium 1·53. By the addition of bichloride of platinum to the solution a copious yellow granular precipitate was produced. Carbazotic acid also occasioned a copious precipitate. Antimoniate of potass occasioned a minute quantity of precipitate.

9. Sulphur. Hydrosulphuric acid was evolved by the action of hydrochloric acid, and the odour of free sulphur was also observed on the application of heat. Weight of slag, after gently heating over a spirit-lamp, 20·13. The nitrous acid process was employed. Sulphate of baryta 0·58.

Analysis tabulated.				Oxygen.
Silica	37·63			19·55
Alumina	12·78			5·97
Lime	33·46	9·40		
Magnesia	6·64	2·48		13·46
Protoxide of manganese	2·64	0·67		
Protoxide of iron	3·91	0·91		
Potass	1·92			0·32
Sulphuret of calcium	0·68			
Error of loss	0·34			
	100·00			

4. Analysis. By D. F.

1. Weight of slag employed 25·38 grains.
2. Silica 9·62.
3. Alumina 3·30.
4. Sulphate of lime 21·43.
5. Phosphate of magnesia 5·09.
6. Oxide of manganese 0·76.
7. Sesquioxide of iron 0·35.
8. Potass. Weight of slag employed 75·68. The weight of the chloride was lost after the calculation of the potass.
9. Sulphur. The process by fusion with nitrate of potass and a mixture of carbonate of potass and soda was adopted. Weight of slag 20·83. Sulphate of baryta 2·45.
10. Phosphoric acid was not detected by the process resorted to in No. 1 (*sup.* p. 353).

Analysis tabulated.				Oxygen.
Silica	37·91			19·69
Alumina	13·01			6·08
Lime	31·43	8·73		
Magnesia	7·24	2·81		12·27
Protoxide of manganese	2·79	0·52		
Protoxide of iron	0·93	0·21		
Potass	2·60			0·44
Sulphuret of calcium	3·65			
Error of loss	0·44			
	100·00			

5. Analysis. By D. F.

1. Weight of slag 25·76 grains.
2. Silica 10·18.
3. Alumina 3·89.
4. Sulphate of lime 21·23.

5. Phosphate of magnesia 2·45.
6. Oxide of manganese 0·80.
7. Sesquioxide of iron 0·61.
8. Potass. Weight of slag 27·52. Chloride of potassium 0·46.
9. Sulphur. The fusion process was adopted. Weight of slag 22·63. Sulphate of baryta 1·54.
10. Phosphoric acid was sought for by the process previously mentioned, but not a trace was detected even after standing a week.

Analysis tabulated.				Oxygen.
Silica	39·52			20·50
Alumina	15·11			7·06
Lime	32·52		9·60	12·05
Magnesia	3·49		1·35	
Protoxide of manganese	2·89		0·64	
Protoxide of iron	2·02		0·46	
Potass	1·06			0·17
Sulphuret of calcium	2·15			
Error of loss	1·24			
	100·00			

6. Analysis. By J. P.

1. Weight of slag employed 19·78 grains, after drying *in vacuo* over sulphuric acid for twenty-four hours.
2. Silica 8·32.
3. Alumina 2·62.
4. Sulphate of lime 15·9.
5. Phosphate of magnesia 0·57.
6. Oxide of manganese 0·48.
7. Sesquioxide of iron 1·09.
8. Potass. Weight of slag, after drying *in vacuo* during twenty-four hours over sulphuric acid, 20·44 grains. Chloride of potassium 0·87.
9. Sulphur. Hydrosulphuric acid was evolved by the action of hydrochloric acid. Weight of slag 20·01 grains. The fusion process was adopted. Sulphate of baryta 0·65.
10. Phosphoric acid. The alumina and oxide of iron obtained in the preceding analysis were fused for a considerable time with bisulphate of potass. The mass was digested with hydrochloric acid; some flocculent matter remained undissolved. To the solution tartaric acid was added, and afterwards chloride of magnesium and excess of ammonia. Two days afterwards minute crystalline particles were observed adhering to the glass. On examination with a simple microscope, the well-known star-shaped crystals of phosphate of magnesia and ammonia were immediately recognised. The solution was allowed to stand several days afterwards. The minute quantity of crystals was collected on a filter, and washed with cold ammonia-water, until no sensible residue was left by evaporation on a plate of glass. After incineration the phosphate of magnesia weighed 0·06. The phosphoric acid is admitted to exist in combination with the alumina.

Analysis tabulated.			Oxygen.
Silica	42·06		20·81
Alumina	12·93		6·05
Lime	32·53	9·14	11·18
Magnesia	1·06	0·41	
Protoxide of manganese	2·26	0·51	
Protoxide of iron	4·94	1·12	
Potass	2·69		0·46
Phosphoric acid 0·19, Alumina 0·12	0·31*		
Sulphur 0·45, Calcium 0·58	1·03		
Error of loss	0·19		
	100·00		

From an examination of the preceding analyses, it is evident that the following formula is the correct expression of the composition of this series:—

$$Al^2O^3,\ SiO^3 + 2\,(3(Ca,\ Mg,\ Mn,\ Fe)\,O,\ SiO^3).$$

The formula differs from that of Vesuvian, in containing two equivalents of the silicate of lime series instead of one. Ivanov however has described a mineral from Slatoust, identical in composition with the preceding slags (Rammelsberg, Part 2. p. 258, and first supplement, p. 151); but Professor H. Rosé informs us that the analysis of Ivanov has been clearly proved erroneous. Berthier has given the results of several analyses of slags from blast furnaces of nearly the same composition, but has incorrectly deduced the formula "(Ca, Mg, M, f) S + AS," which is that of Vesuvian. He has also omitted in his analysis of a slag from Dudley, protoxide of manganese, potass and sulphur, which were found in all the preceding analyses of slags from the same locality.

7. Analysis. By J. P.

This slag was obtained from one of Mr. Dawes's hot-blast furnaces at Oldbury. It was found mixed with coke and other matters; it contains globules of iron, and sulphur may be readily observed deposited here and there upon the crystalline plates.

The crystals are thin square plates, the lateral faces of which are perpendicular to each other, and to the terminal faces. They appear to belong to the pyramidal system. They are white, and when very thin transparent.

Hardness $= 5{\cdot}7$.

7. Analysis *a*. By J. P.

1. Weight of slag, after heating carefully over a spirit-lamp to expel the free sulphur 20·19.
2. Silica 5·71.
3. Alumina 4·89.
4. Sulphate of lime 20·97.
5. Phosphate of magnesia 1·64.
6. Oxide of manganese 0·016.
7. Sesquioxide of iron 0·06.
8. Potass. After heating to expel the free sulphur, weight of slag 14·74. Chloride of potassium 0·15. The presence of soda in minute quantity was also clearly detected, as follows:—

a. By heating before the blowpipe a platinum wire, and making a com-

* Estimated as $2Al^2O^3,\ 3PO^5$ $(51{\cdot}44 \times 2 + 55{\cdot}44 \times 3)$.

parative experiment with platinum wire alone, a *decided yellowness* indicative of soda was observed.

b. By the addition of the solution of antimoniate of potass to a few drops of the solution on a watch-glass, a minute quantity of precipitate appeared.

9. Sulphur. Hydrosulphuric acid was copiously evolved by the action of hydrochloric acid. Sulphur existed in three states, free, combined as sulphuret, and also as sulphuric acid. The free sulphur was not estimated. The nitrous acid process was adopted. 14·74 grains, weighed after expulsion of the sulphur by heat, furnished of sulphate of baryta 1·71. By a second determination of sulphur 13·01 grains, heated as before, and treated with nitrous acid, gave of sulphate of baryta 1·58. By the first total sulphur..... 1·60 per cent.

By the second..... 1·67 ....

Mean ..... 1·63 ....

Sulphur as sulphuric acid. 9·72 grains heated as before to expel free sulphur, were digested with hydrochloric acid. Evaporation to dryness was omitted, and the solution was immediately filtered; baryta water was added to the filtrate. The sulphate of baryta weighed 0·104. This, by tables, corresponds to 0·37 per cent. of sulphuric acid, and to 0·15 of sulphur. The whole amount of sulphur is 1·63. Therefore 1·63—0·15=1·48 is the sulphur combined as sulphuret.

10. Phosphoric acid was not sought for.

7. Analysis *b*. By J. P.

1. Weight of slag, after treating as before, 20·31 grains.
2. Silica 5·76.
3. Alumina 4·93.

An accident occurred in the determination of the lime.

7. Analysis *c*. By J. P.

1. Weight of slag, after heating as before, 20·23 grains.
2. Sulphate of lime 20·77.
3. Phosphate of magnesia 1·44.

Analysis tabulated.

	a.	*b*.	*c*.	Mean.		Oxygen.
Silica	28·28	28·36	.....	28·32		14·71
Alumina	24·22	24·27	.....	24·24		11·33
Lime	40·39	.....	39·96	40·12	11·27	
Magnesia	2·94	.....	2·62	2·79	1·08	12·42
Protoxide of manganese	0·07	.....		0·07	0·01	
Protoxide of iron	0·27	.....		0·27	0·06	
Potass with trace of soda	.....	.....	.....	0·64		0·11
Sulphate of lime	.....	.....	.....	0·26		
Sulphuret of calcium	.....	.....	.....	3·38		
				100·09		
Error of excess	.....	.....	.....	0·09		

This interesting specimen approximates very nearly in composition to Gehlenite, of which we introduce the following analyses for comparison (see Rammelsberg).

	Fuchs.	Oxygen.	Crystallized by V. Kobell.
Silica	29·64	15·38	31·0
Alumina	24·80	11·58	21·4
Lime	35·30	11·90	37·4
Magnesia	—		3·4
Oxide of iron (eisen oxyd oxydul)	6·56	FeO	4·4
Water	3·30		2·0
	99·60		99·6

	Damour.	Oxygen.	
Silica	31·60	16·18	
Alumina	19·80	9·24	11·03
Sesquioxide of iron	5·97	1·79	
Lime	38·11	10·83	11·76
Magnesia	2·20	0·85	
Soda	0·33	0·08	
Water	1·53		
	99·54		

	Slag 7. J. P. Oxygen.	Native Gehlenite. *Fuchs.* Oxygen.	Native Gehlenite. *Damour.* Oxygen.
Silica	14·71	15·38	16·18
Alumina bases	11·33	11·58	11·03
Lime bases	12·42	11·90	11·76

In slag 7 we may probably be justified in regarding the sulphate of lime and sulphuret of calcium as impurities, and in no way connected with the formula; just as the water, which appears to exist in natural Gehlenite in variable proportion, may be similarly regarded. Metallic iron and fragments of coke being mixed up in the slag, the crystalline plates were carefully selected as free from impurity as possible.

The oxygen of the silica is to the oxygen in either the alumina or lime bases in the proportion of 4 to 3. This leads to the formula

$$3(3CaO,\ SiO^3)+3Al^2O^3,\ SiO^3,$$

or as represented by Berzelius's method of notation,

$$3\dot{C}a^3\,\ddot{S}i+\underline{\ddot{A}l}^3\,\ddot{S}i,$$

which also appears to represent the constitution of Gehlenite more nearly than $2\dot{C}a^3\,\ddot{S}i+\underline{\ddot{A}l}^2\,\ddot{S}i$, which is usually assigned to it (Rammelsberg, Handwörterbuch, Theil i. p. 250; second supplement, p. 53).

By contracting the following calculations from the respective formulæ this statement will appear clear.

1. $3\dot{C}a^3\,\ddot{S}i+\underline{\ddot{A}l}^3\,\ddot{S}i$		Oxygen.	2. $2\dot{C}a^3\,\ddot{S}i+\underline{\ddot{A}l}^2\,\ddot{S}i$	Oxygen.
$\ddot{S}i$	30·86	16·02	33·60	17·44
$\underline{\ddot{A}l}$	25·89	12·07	24·93	11·65
$\dot{C}a$	43·67	12·08	41·49	11·63

$\ddot{S}i$ is taken as 46·22, $\underline{\ddot{A}l}$ as 51·44, and $\dot{C}a$ as 28·52.

We are unable to conjecture why the latter formula should have been preferred to the former, unless because the combination $\dddot{\underline{Al}}^3$, $\dddot{Si}$ was supposed improbable; examples however of such a combination are afforded by Kollyrite $\dddot{\underline{Al}}^3\dddot{Si}+15\dot{\underline{H}}$, Heterokline $\dddot{\underline{Mn}}^3\dddot{Si}$, and Sismondine $4\dot{Fe}^3\dddot{Si}+5\dddot{\underline{Al}}^3\dddot{Si}+15\dot{\underline{H}}$.

We may also call attention to the fact, that the slag in question has the same hardness as natural Gehlenite.

Admitting this slag to be really Gehlenite, the circumstance of its production at a high temperature in an iron furnace, may possibly be made available by the geologist in explaining the formation of the rocks in which the natural mineral occurs in Fassathal in the Tyrol. We subjoin in a note the following interesting description of the locality of Gehlenite by Von Buch, translated by Mr. Warington Smyth, of the Museum of Economic Geology*.

8.

This specimen was also presented to us by Mr. Dawes. It was obtained during the process of remelting cast iron with lime in a small cupola.

No. 8 is a mass of pearl-gray slag containing imbedded long yellow crystals which appear to be square prisms with the angles truncated, cleavable perpendicular to the axis of the prism. In part of the specimen the crystals are very fine and radiated.

8. Analysis. By D. F.

Nitrous acid was employed, instead of hydrochloric, to decompose this slag. Magnesia and potass were not present. After the precipitation of the

* The syenite of Mount Monzon descends steeply from the snow limit, and is very like the zircon syenite of Norway. The hornblende is green, and accompanied by grains of iron pyrites. Tourmaline also appears there in crystals, radiating from a centre. In cracks and hollows of this syenite are found Vesuvian, Gehlenite, brown garnet, Ceylanite and Fassaite, a sort of augite.

In ascending the branch valley from Vigo to Monzon (see plan) fine cliffs of dolomite are seen on both sides, and on the left the augitic porphyry, or melaphyre, is seen to underlie it; higher up the whole valley is strewed with blocks of syenite fallen from the Alp above.

From beneath the height may be seen a thick bed of Vesuvian, from which fragments often fall, though no one has as yet been able to ascend to it; its crystals are four-sided prisms with the terminal faces much-modified, and are always imbedded in calc spar, generally of a blue colour.

Cordier considered that the Gehlenite is only Vesuvian with its crystallization impeded by the presence of calc spar. There are also brown crystals enveloped in calc spar, with neither end free, and these are undistinguishable from Vesuvian. When they form groups together, they lose lustre and colour, and the calc spar disappears. The only place where it is found is quite on the west side of the syenite, close to the dolomite; for it is only near the edges that calc spar, which always accompanies these foreign minerals, is found in the syenite.

Above the Vesuvian and Gehlenite are fine druses of Ceylanite in crowded and generally good dark octohedrons; which were probably at first also imbedded in calc spar, since a little of it, with corroded surface, sometimes lies among the crystals. In a similar manner the sort of augite termed Fassaite lies in calc spar; when fresh the crystals are fine grass-green: this augite is often found on the sides of Vesuvian crystals.

At Monzon the cracks are often covered with fine rhombohedrons of chabasite, and sometimes are slight traces of mesotype, the only zoolites found here; though among the other zoolites in the Fassa valley chabasite is not found.

The relations of this syenite to the red sandstone and to the porphyry are difficult to determine, from the great steepness of the mountain on the south side also.

lime, the sulphuric acid, produced by the oxidation of the sulphur existing as sulphuret, was determined by the addition of acetate of baryta.

1. Weight of slag 25·46 grains.
2. Alumina 2·95.
3. Sulphate of lime 24·27.
4. Oxide of manganese 0·25.
5. Sesquioxide of iron 0·34.
6. Sulphate of baryta 1·44.

Analysis tabulated.	Per cent.		Oxygen.
Silica	45·59		23·68
Alumina	11·88		5·18
Lime	38·20	10·73	
Protoxide of manganese	0·91	0·20	11·18
Protoxide of iron	1·11	0·25	
Sulphuret of calcium	1·76		
Error of loss	0·55		
	100·00		

Without attempting to extort from the preceding analytical results a precise atomic expression, we may state that probably the formula of Humboldtilite, as deduced from the analysis of Von Kobell (Rammelsberg, 2nd part, p. 308), nearly represents the constitution of this slag. The formula in question is

$$3\,\dot{R}^3\,\ddot{S}i + \dot{R}\,\ddot{S}i.$$

We introduce Von Kobell's analysis (Rammelsberg, 1st part, p. 314):—

			Oxygen.
Silica	43·96		21·83
Lime	31·96	8·97	
Magnesia	6·10	2·36	11·86
Protoxide of iron	2·32	0·53	
Alumina	11·20		5·23
Soda	4·28		1·09
Potass	0·38		0·06
	100·20		

The per-centage composition calculated from the formula would be,—

Silica	45·37
Alumina	12·62
Lime	41·99
	99·98

Damour assigns a different formula for Humboldtilite, which he believes to be identical with Mellilite*; and this formula is precisely that which we have given for the first series of blast-furnace slags. For the sake of comparison we subjoin Damour's analyses.

	Mellilite.		Oxygen.		Humboldtilite.	
Silica	39·27		20·40	40·69		21·13
Alumina	6·42	2·99	6·10	4·43	2·06	5·39
Sesquioxide of iron	10·17	3·11		10·88	3·33	
Lime	32·47	9·12	11·62	31·81	8·92	11·14
Magnesia	6·44	2·50		5·75	2·22	
Potass	1·46		0·24	0·36		0·06
Soda	1·95		0·52	4·43		1·12
	98·18			98·35		

* Rapport Annuel sur les Progrès de la Chimie, le 31 Mars, 1844. 5ième année. Par J. Berzelius, p. 173. Paris, 1845.

Berzelius remarks that "in designating by r the bases with 1 atom of oxygen, and by R the bases with 3 atoms of oxygen, the formula $2r\,S + R\,S$ will be obtained, which expresses a somewhat rare kind of composition."

9 and 10.

The two following specimens were communicated by M. Krantz, the well-known mineralogist of Berlin. They were labelled, Olsberger Furnaces, on the Rhine.

No. 9 contains a drusy cavity with projecting crystals, which are not sufficiently bright for measurement with the reflective goniometer. They appear to belong to the oblique prismatic system. They have a single end-face which is not at right angles to the axis of the prism. Hardness = 5. No. 10 is a mass exhibiting a radiated crystalline structure, the individuals of which are too small for measurement. Hardness = 5·7.

To one side of each of these specimens are attached minute scales of graphite.

9. Analysis *a*. By J. P.

The three following slags not being decomposable by hydrochloric acid, the method of fusion with a mixture of equal parts of carbonate of potass and soda* was resorted to.

1. Weight of slag 20·16 after heating over a spirit-lamp and cooling over SO^3. Being extremely hard, it was broken between writing-paper on an iron plate, further reduced in a steel mortar, and finally triturated in an agate mortar, and levigated until the whole piece detached was reduced to impalpable powder. It was fused with 80 grains of the carbonate of potass-soda mixture. The fused mass had a blue-green colour.
2. Silica 10·74.
3. Alumina 1·02.
4. Sulphate of lime 14·88.
5. Phosphate of magnesia 5·21.
6. Oxide of manganese 0·31.
7. Sesquioxide of iron 0·23.
8. Potass. Weight of slag 50·51 grains. Fused with 200 grains of carbonate of baryta and proceeded in the usual way. This alkali was distinctly recognised by the following tests:—
   - *a*. Bichloride of platinum produced the characteristic yellow granular precipitate.
   - *b*. Carbazotic acid, after the lapse of a short time, produced the characteristic crystals of carbazotate of potass.
   - *c*. No indication of the presence of soda was furnished by antimoniate of potass.

A source of error occurring, the weight of the chloride of potassium was not determined; however, it is certain that the quantity must have been very small, less than in any of the preceding analyses.

9. Sulphur existed combined as sulphuret in minute quantity. By the action of hydrochloric acid a slight evolution of gas was occasioned, but it had the odour of hydrogen (from particles of iron detached from the steel mortar?), obtained by the action of an acid on iron; the odour of hydrosulphuric acid could not be distinctly recognised; yet on suspending for some time a piece of moistened acetate of lead-paper at the top of a test-tube containing

* Prepared by calcination of pure tartrate of potass and soda.

some of the powder of the slag and hydrochloric acid, blackening was slowly produced. No quantitative determination of sulphur was made.

10. Phosphoric acid. The precipitate obtained by ammonia (8 in the potass examination) was dissolved in hydrochloric acid, tartaric acid was added, and then excess of ammonia, and finally chloride of magnesium. After standing many days not a trace of crystalline precipitate could be detected.

9. Analysis *b*. By J. P.

1. Weight of slag 20·21 grains. Fused with 100 grains of the carbonate of potass-soda mixture.
2. Silica 10·81.
3. Alumina 1·05.
4. Sulphate of lime 14·97.
5. Phosphate of magnesia 5·26.
6. Sesquioxide of iron 0·20.

Analysis tabulated.	*a*.	*b*.	Mean.	Oxygen.
Silica	53·27	53·48	53·37	27·72
Alumina	5·06	5·19	5·12	2·81
Lime	30·65	30·78	30·71	8·62
Magnesia	9·47	9·54	9·50	3·67
Protoxide of manganese	1·41	..	1·41	0·31
Protoxide of iron	1·02	0·89	0·95	0·21
			101·06	

10. Analysis. By D. F.

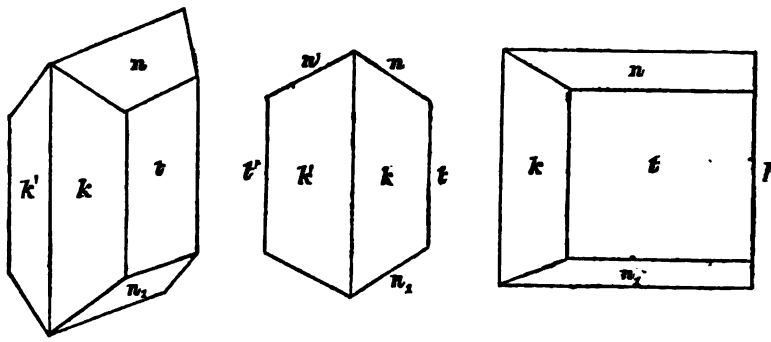
1. Weight of slag 17·54 grains. Fused with 80 grains of the carbonate of potass-soda mixture.
2. Silica 9·43.
3. Alumina 0·84.
4. Sulphate of lime 12·43.
5. Phosphate of magnesia 4·70.
6. Oxide of manganese 0·24.
7. Sesquioxide of iron 0·29.
8. Potass. The slag was decomposed by digestion with fluoride of calcium and sulphuric acid. Potass was not detected.

Analysis tabulated.		Oxygen.
Silica	53·76	27·93
Alumina	4·76	2·22
Lime	29·48	8·28
Magnesia	9·82	3·80
Protoxide of manganese	1·30	0·29
Protoxide of iron	1·48	0·34
	100·60	

With the exception of a few small crystals in a drusy cavity in No. 9, the crystallization of the two preceding slags is confused, so that we could scarcely hope to deduce from their composition a satisfactory formula. The oxygen of the acid being nearly double that of the bases, the slag is formed of bisilicates, and evidently approximates very nearly in composition to some varieties of augite (pyroxene) containing alumina. Several analyses of augite giving about the same per-centage of alumina may be found in the first part of

The surface of this slag is covered with bright black crystals, exhibiting occasionally an iridescent tarnish. The crystals belong to the prismatic system. The normals to the faces make the following angles with each other:—$n\,n' = 49° 24'$, $n\,t = 65° 18'$, $k\,k' = 98° 24'$, $k\,t = 40° 48'$. They cleave readily parallel to a plane p, which is perpendicular to the faces t, n, n', and makes equal angles with the faces k, k'.

Hardness = 6. At 18°·6 C. $\frac{\text{specific gravity of slag}}{\text{specific gravity of water}} = 4·0805$.



13. Analysis. By J. P.

This slag was found to contain silica, protoxide and sesquioxide of iron, protoxide of manganese, alumina, lime, magnesia, sulphur as sulphuret, and phosphoric acid. It was decomposed by long digestion with dilute hydrochloric acid. The silica, however, obtained by this means was more or less gray; and in order to obtain it perfectly white, it was fused with the carbonate of potass-soda mixture, and the fused mass, which had a bluish-green colour, was decomposed with hydrochloric acid. The solution was treated with nitric acid to peroxidize the iron; ammonia was then added in slight excess, and the analysis continued in the manner formerly described. The proportion of the two oxides of iron, the phosphoric acid and the sulphur, were determined by separate analyses, as will be described in the sequel.

1. Weight of slag 20·20 grains, after drying *in vacuo* over SO^3 during 48 hours.

2. Silica 5·98. Repeated by Mr. Forbes; 20·14 grains of slag gave 5·99.

3. Total amount of iron obtained as $Fe^2 O^3$, 14·63. The oxide of iron contained a minute quantity of $P^2 O^5$, which was not removed by boiling with potass; for on redissolving the iron in hydrochloric acid, adding excess of tartaric acid and afterwards excess of ammonia, and lastly, chloride of magnesium, a few minute crystalline grains appeared after standing some days. However, this error of excess must be very small.

4. Oxide of manganese 0·256.

5. Alumina 0·53. As the alumina was precipitated from its solution in presence of $P^2 O^5$, and as only a minute quantity of this acid was retained by the iron, the whole amount of $P^2 O^5$ may be subtracted from the alumina. The total $P^2 O^5$ obtained (vide sequel) was 1·34 per cent.

20·2 (slag) : 0·53 : : 100 : 2·62.

2·62 − 1·34 = 1·28 alumina.

Taking the phosphate alumina as $4Al^2 O^3$, $3P^2 O^5$ (see Rapport Annuel,

Berzelius, 7ième année, p. 127, and Graham's Chemistry), 2·62 of the salt would contain 1·28 of alumina.

6. Sulphate of lime 0·23.

7. Phosphate of magnesia 0·19.

8. Sulphur. This determination was made by Mr. Forbes by fusion with nitrate of potass and the carbonate of potass-soda mixture. 20·14 grains gave of sulphate of baryta 0·87. The odour of hydrosulphuric acid could not be detected by the action of hydrochloric acid upon the powder of the slag; but on suspending for some time a slip of moistened acetate of lead paper in a test tube containing some of the powder of the slag and hydrochloric acid, it became slightly brown. Now, as the slag contains sesquioxide of iron, the hydrosulphuric acid liberated by the action of hydrochloric acid upon any sulphuret which may be present, would evidently be immediately decomposed, with the separation of free sulphur, by the sesquichloride of iron which would be formed at the same time; and, accordingly, free sulphur was always distinctly recognised by its odour in drying the silica obtained from slags of this group. It may perhaps appear somewhat remarkable that sulphuret of iron and sesquioxide should exist together in the same slag; the fact however is certain. It may be that the sulphuret is irregularly diffused, and is, as it were, entangled in the mass. No trace of sulphuric acid could be detected by the addition of baryta water to the solution of the slag in hydrochloric acid, even after standing 24 hours.

9. Sesquioxide of iron. About 10 grains were digested in dilute hydrochloric acid in a well-stopped flask over the water-bath. The necessary precaution of previously filling the flask with carbonic acid was carefully observed. The clear supernatant liquor was decanted rapidly into a stoppered phial containing excess of the solution of chloride of gold and sodium. The phial was well-closed and left for several days. The metallic gold weighed 3·93, which by the tables corresponds to 4·16 FeO. The filtrate was deprived of the excess of gold by digestion with oxalic acid. The iron was precipitated by hydrosulphate of ammonia; redissolved in hydrochloric acid; peroxidized by chloride of potass, and precipitated by ammonia; the precipitate was boiled with potass, redissolved in hydrochloric acid, and precipitated by succinate of soda with the usual precaution. The sesquioxide of iron weighed 5·76, but from this must be deducted 4·16 FeO, estimated as Fe^2O^3=4·63; 5·76—4·63=1·13 iron existing as Fe^2O^3. The ratio of FeO to Fe^2O^3 is 4·16 : 1·13. The total amount of iron estimated as Fe^2O^3 is 72·42 per cent. 5·76 : 1·13 : : 72·42 : 14·20. But 0·60 of S, as sulphuret, was present, which, by tables, gives 2·91 Fe^2O^3. The total amount of Fe^2O^3 per cent. is 14·20+2·91=17·11 . 72·42—17·11=55·31 Fe^2O^3=49·73 FeO, from which must be subtracted a quantity of Fe proportionate to 0·60 S. This quantity is 1·01—1·01+0·60=1·61=quantity of FeS. 1·01 corresponds to 1·30 FeO. 49·73—1·30=48·43=total FeO per cent.

Fe as FeO 48·43
Fe as Fe^2O^3 17·11
Fe as FeS 1·61

10. Phosphoric acid. Weight of slag 20·10. Proceeded to obtain a solution in hydrochloric acid free from silica in the usual way. The tartaric acid process was adopted. The whole was allowed to stand several days. The ammoniaco-magnesian phosphate was washed with cold ammonia water. Phosphate of magnesia 0·42. Colour pale brown from a trace of manganese. Every trace of carbon was burnt out.

Analysis tabulated.			Oxygen.
Silica	29·60	.....	15·37
Protoxide of iron	48·43	.....	11·02
Sesquioxide of iron	17·11	.....	5·24
Protoxide of manganese*	1·13	.....	0·25
Alumina	1·28	.....	0·59
Lime	0·47	.....	0·13
Magnesia	0·35	.....	0·13
Phosphoric acid	1·34	.....	0·75
Sulphuret of iron	1·61		
	101·32		

These crystals closely resemble olivine in their form. The faces of the crystals are denoted by the same letters as the faces of olivine in Naumann. *t*, *k*, *n* of Naumann correspond to *p*, *c*, b_2 of Phillips respectively.

Crystals similar to these in form, composition and mode of occurrence, were described by Mitscherlich in the Annales de Chimie, t. xxiv. Measurements of crystals of the same form, and a comparison of their angles with those of olivine, were given by one of the authors (W. H. M.) of the report in the third volume of the Transactions of the Cambridge Philosophical Society.

Estimating the whole of the iron as protoxide, the composition would be nearly that of $\dot{Fe}^3\ddot{S}i$, the formula assigned by Thomson to the mineral from Ireland, named "Anhydrous silicate of iron." Now, this slag had evidently been in a position favourable to the absorption of oxygen, namely, the flue of a puddling furnace; and we shall probably be justified in supposing that, after crystallization as silicate of protoxide of iron, oxygen may have been absorbed, and that the crystal may consequently be regarded to a certain extent pseudomorphous. In the case of the following slag, which is similar to the one in question, it was found by experiment that the powder of the slag readily absorbed oxygen by calcination in the air. If this view be admitted, the slag will in constitution as well as form resemble olivine, the magnesia of the latter being replaced by protoxide of iron.

14.

This slag was found by Mr. Twamley at the Bloomfield iron-works, Tipton, in a heap of calcined puddling furnace slag, technically called "tap cinder." The proprietors of these works have secured by patent the application of calcined tap cinder for the beds of puddling furnaces. It is stated that, by the process of calcination, which is conducted in large kilns similar to brick-kilns during a fortnight or three weeks, the slag is rendered much less fusible, and is therefore well-adapted to the purpose to which it is applied. The analysis will probably explain this fact. The heat of the kilns appears, from an examination which one of us has made (J. P.), to be sufficient to soften and agglutinate the pieces of slag together, but not to effect perfect fusion.

This slag is a mass of large iron-gray crystals, the faces of which though even are much too dull to be measured with the reflective goniometer. The general resemblance of their forms, however, to those of No. 12 is so close as to leave no doubt of their crystalline identity.

At 18·2° C. Specific gravity = 4·1885.

It attracts the magnetic needle strongly.

* Probably a portion existed as a superior oxide.

14. Analysis. By J. P.

This slag was found to contain the same constituents as the one preceding, and the analysis was conducted in a similar manner.

1. Weight of slag 21·00 grains.

2. Silica 5·01 grains.

3. Total amount of iron obtained as Fe^2O^3 14·44.

The oxide of iron in this case after boiling with KO twice, was redissolved in HCl and precipitated by hydrosulphate of ammonia.

4. Oxide of manganese 1·39. The manganese was precipitated as MnO^2 by chlorine and ammonia.

5. Alumina with phosphoric acid 1·87. The Al^2O^3 was precipitated from a solution containing much more P^2O^5 than required for saturation, for the greater part of the P^2O^5 had been dissolved out of the iron precipitate by KO. This fact was confirmed in another case by dissolving the oxide of iron after treatment by KO in HCl and digesting with excess of hydrosulphate of ammonia, and testing the filtrate for P^2O^5. Admitting the phosphate of alumina, as precipitated by ammonia, to be $4Al^2O^3, 3P^2O^5$ (Rammelsberg, Rapport Annuel, Berzelius, 7ième année, p. 127), the calculated proportion of alumina is 0·91.

6. Sulphate of lime 0·136.

7. Phosphate of magnesia 0·139.

8. Sulphur. The observations upon this element in the preceding analysis exactly apply to the present. 26·14 grains of slag were fused with 50 of nitrate of potass and 100 of the carbonate of potass-soda mixture. Sulphate of baryta 0·44.

9. Sesquioxide of iron.

1. By chloride of gold and sodium process. Weighed roughly 10 grains. Proceeded precisely as in the former analysis. Metallic gold 3·32. Total quantity of iron as Fe^2O^3, 5·85.

2. By Fuchs's method with pure copper. The necessary precautions concerning the exclusion of air during solution, &c. by carbonic acid, were carefully attended to. The copper was left in the solution during several days, until the latter had become colourless. Weight of slag 25·83 grs. A piece of electrotype sheet-copper was used; before immersion it weighed 18·176, afterwards 15·815 grs.

Fe^2O^3 per cent. by the first method	22·65
Ditto second	22·61

But the slag contains 0·28 per cent. of sulphur, which corresponds to 1·12 per cent. of Fe^2O^3. From the preceding data the following results are obtained:—

Fe as FeO.....	39·83
Fe as Fe^2O^3	23·75
Fe as FeS.....	0·62

10. Phosphoric acid.

1. By the tartaric acid process. Weight of slag 25·83. The solution used in the Fe^2O^3 determination by Cu was employed. The phosphate of ammonia and magnesia having a brown colour, it was redissolved and reprecipitated by ammonia. Phosphate of magnesia 2·76.

2. The solution obtained in the sulphur determination was also employed. Weight of slag 26·14. Phosphate of magnesia 2·66.

P^2O^5 per cent. by the first method	6·40
Ditto second	6·45
Mean.....	6·42

11. Our friend T. H. Henry, Esq. of London, determined the proportions of several of the ingredients of this slag, and has communicated to us the following results:—

Si O^3 23·77 per cent. Fe O 40·07. Fe^2 O^3 22·68 (quantity corresponding to sulphur not added). Al^2 O^3 with P^2 O^5 1·6. P^2 O^5 6·40.

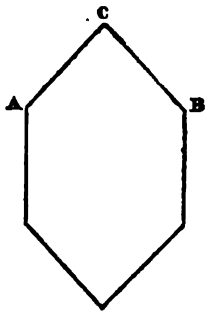
Analysis tabulated.			Oxygen.
Silica	23·86	.....	12·41
Protoxide of iron	39·83	.....	9·07
Sesquioxide of iron	23·75	.....	7·28
Protoxide of manganese	6·17	.....	1·38
Alumina	0·91	.....	0·42
Lime	0·28	.....	0·08
Magnesia	0·24	.....	0·09
Phosphoric acid	6·42	.....	3·60
Sulphuret of iron	0·62		
	102·08		

We regard this slag as similar in constitution to the preceding, the alumina, some of the sesquioxide of iron, and the phosphoric acid being present as impurity. The presence of so large a quantity of sesquioxide of iron in this slag is probably to be explained by its long exposure in the kiln, during which it was in a condition favourable to the absorption of oxygen. The powder of the slag, when heated to redness in a platinum crucible, changes colour, acquiring a brown tint, and increases in weight. The quantity of phosphoric acid is also remarkable, and is well-deserving of the attention of those engaged in the smelting of iron. Berthier has given the analysis of a refinery slag from Dudley (Traité des Essais, t. 2. p. 289), containing 7·2 per cent. of phosphoric acid. It is found that when puddling furnace slag (tap cinder) is worked with the ordinary ores of iron, such as argillaceous ore and hæmatite, the iron is liable to be "cold short," or possess that property which is known to be dependent upon the presence of phosphuret of iron. Now it is evident that in smelting tap cinder, which will probably always be found to contain a sensible amount of phosphoric acid, the manufacturer will be introducing into the furnace the very element, in a concentrated form, which it is one object of the puddling furnace to remove, namely, phosphorus. An immense quantity of iron slag, far richer than many iron ores, is annually thrown away, and it may be that the presence of phosphorus in sensible quantity is one of the causes which prevents the resmelting of this slag with advantage. This fact has not yet sufficiently attracted the attention of those engaged in the manufacture of iron. The discovery of a method of extracting economically good iron from these rich slags would be of great advantage to the country, and could not fail amply to reward its author.

15.

The history of this slag is doubtful; though it is probable that it was produced in a puddling furnace. It has not yet been analysed; yet we introduce the results of its crystallographic examination in order to illustrate a new process of admeasurement of crystals of this kind, by W. H. M.

One side of this piece of slag is bounded by a plane smooth surface, on which are traced the outlines of a number of crystals packed close together, separated by [illegible]d slag. Some of the outlines of crystals are rectangl[illegible]g their obtuse angles cut off by parallel lines.

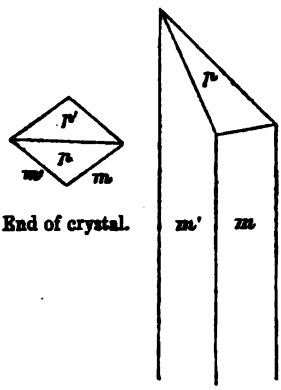


An attempt was made to measure approximately the acute angle of the rhomb in the following manner:— By means of a stout branch with an universal joint like that of Wollaston's goniometer, the slag was attached to a common six-inch circular protractor graduated to half degrees, with its plane surface upwards, and parallel to the plane of the protractor. The protractor was placed upon a table, having traced upon it a fine straight line longer than the diameter of the protractor. A compound microscope, having a spider line in the focus of the eye-piece, was firmly fixed with its axis perpendicular to the table, and at such a distance from it as to command distinct vision of the plane surface of the slag. By moving the protractor with the slag attached to it till the images of the sides of the rhomb formed in the microscope successively coincided with the spider line, and reading off the degrees and minutes at which the protractor met the line traced on the table, the angle is obtained through which the protractor has been turned between the two observations; or, the angle of the rhomb. The values of the angle A C B thus observed were,— 77°·0, 79° 45′, 81° 30′, 80°, 78° 15′, 79° 15′, 77° 45′, 78° 20′, 82° 6′, 80° 50′, 77° 30′, 80°, 80° 15′. Such a method of observation is obviously insufficient for the identification of a crystalline species; yet renders it probable that these crystals are the same as No. 13, a section of which, by a plane perpendicular to $k\,k'$, would produce a rhomb of 81° 36′.

At 18°·1 C. specific gravity of slag = 3·9984.

We conclude our present report by the crystallographic description of an interesting slag obtained from the gold and silver refinery of Messrs. Betts of Birmingham. The matrix is very heavy, and probably differs considerably in composition from the minute crystals in question, which appear to be, as it were, sublimed upon the surface, and of which it is impossible to obtain sufficient for analysis.

Crystal in profile.



The surface of this is studded with numerous extremely small black bright crystals belonging to the oblique prismatic system. The angles between normals to the faces are $m\,m'$ 73° 10′, $p\,p'$ 86°, $m\,p$ 29° 42′. The edge in which $p\,p'$ intersect makes an angle of nearly 46° 30′ with the intersection of m, m'*. For a portion of the slag having crystals adhering to it, at 19°·1 C. specific gravity of slag = 6·3802.

We have remaining an extensive series of slags from various metallurgical works, which we have not yet had time to investigate, but we hope to be able to continue our labours in this department, and to present to the Association a second report at no distant period. We have several specimens of beautifully crystallized octahedral or magnetic oxide of iron, and many other crystals from the copper furnaces. We take this opportunity of p[illegible] thanking those gentlemen who have obligingly contributed to our co[illegible] and of inviting any others, who may have the opportunity, to fu[illegible] views in a similar manner by the contribution of specimens.

* I cannot find any mineral having the same or nearly the same an[illegible]

Addenda to Mr. Birt's Report on Atmospheric Waves.

The following table exhibits the distribution of pressure on the transit of the crest of the great wave, Nov. 18, 1842, with especial reference to the wave, crest No. 4, including St. Petersburgh as a station.

TABLE XVII.

Barom. Phase.	Station.	Altitude.		Wave Phase.
Min.	The Orkneys ...	30·18		
	Cork.....	30·18		
	Belfast	30·37		Posterior Slope.
	Shields	30·42		
	Bristol	30·42		
	Plymouth.....	30·47		
Max.	London	30·53...	A	Crest.
	Paris	30·38		Anterior Slope.
	Christiania	30·11		
Min.	St. Petersburgh..	29·85		

A the highest reading at these stations on this day.

Altitude of anterior slope. St. Petersburgh to London ·68
(A very oblique section.)

Altitude of posterior slope. Cork to London ·35
(The posterior trough was doubtless some distance north-west of Great Britain and Ireland.

November 22. Trough between waves 7 and 9.—The trough now transits St. Petersburgh, crest No. 9 now transits Christiania. We have already noticed that crests 7 and 11 were small waves; abstracting them, we have this succession of large waves thus, Nos. 1, 3, 5, 9. When crest No. 1 traversed England on the 1st, its anterior trough extended beyond St. Petersburgh; when crest No. 3 traversed England on the 10th, its anterior trough also extended beyond St. Petersburgh; when crest No. 5 passed the Orkneys on the 15th, its anterior trough passed St. Petersburgh; and when crest No. 9 passes Christiania (this day), its anterior trough passes St. Petersburgh. These facts clearly show the gradual contraction of the waves or oppositely directed beds of parallel currents.

General Conclusion.

It will be readily apparent from the collation of Mr. Brown's with the St. Petersburgh observations, that the results arrived at in the preceding discussion have been fully confirmed, and there appears to be but little doubt that the waves as determined in the first instance by a discussion of observations from the stations announced in my first report (Report, 1844, page 267), and further identified and illustrated by the observations collected by Mr. Brown, as well as those which have been brought to light by means of Mr. Brown's observations, and confirmed and illustrated by the St. Petersburgh observations, had a *real existence*; an *individuality* has been attributed to certain arrangements of aërial currents and distribution of pressure in connexion with such currents, the aggregate phænomena forming an atmospheric wave. Of the waves thus brought to light, *two* occupy very prominent positions; they stand out as it were from the others; the individuality of each is very striking, and the velocities with which they traversed the area isolate them from their predecessors and exhibit them not as gregarious, but solitary waves. These waves are B° and crest No. 4, the first occurring just previous to the setting-in of the great wave, and the last forming its crown. The wave, crest No. 4, appears from its elevated position on the symmetrical or normal wave, admirably adapted to crown our investigations with success, especially in so far as its amplitude, velocity and path are concerned, we are now, I apprehend, in possession of materials to determine with a considerable approximation to accuracy, these elements. Its longitudinal direction appears to have been very extensive. This element would receive considerable elucidation by means of observations from the south of France, Spain, Portugal and the north of Africa. It is highly probable that this wave in the direction of its length stretched from the extreme south to the very north of Europe.

NOTICES

AND

ABSTRACTS OF COMMUNICATIONS

TO THE

BRITISH ASSOCIATION

FOR THE

ADVANCEMENT OF SCIENCE,

AT THE

SOUTHAMPTON MEETING, SEPTEMBER 1846.

ADVERTISEMENT.

THE EDITORS of the following Notices consider themselves responsible only for the fidelity with which the views of the Authors are abstracted.

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UNIVERSITY OF CALIFORNIA

NOTICES AND ABSTRACTS

OF

MISCELLANEOUS COMMUNICATIONS TO THE SECTIONS.

MATHEMATICS AND PHYSICS.

On the Principle of Continuity in reference to certain Results of Analysis. *By* Professor YOUNG, *Belfast.*

THE principal object of this paper is to examine into the influence of the law of continuity, as it affects the extreme or limiting values of varying functions, and to exhibit some remarkable verifications of the mathematical axiom that "what is true *up to* the limit is true *at* the limit."

Much error and confusion exists in the writings of analysts, more especially in those of Cauchy and Poisson, in consequence of the imperfect views generally entertained in reference to the principle of continuity, whenever extreme or ultimate values of a variable come under consideration. In certain infinite series where the condition of continuity avowedly prevails, it is the common practice to neglect this principle in the limiting cases, and to treat such cases as if they were entirely isolated and unconnected with the general forms to which they really belong; whilst in other classes of series, those namely that have been called periodic, as also in definite integrals involving periodic quantities, it is a practice equally common to *introduce* the condition of continuity where in fact it has no legitimate existence. Many false conclusions have thus obtained currency in analytical writings, and it is the aim of the paper, of which this is a very brief abstract, to inquire into the sources of these errors, and to supply the requisite corrections.

As respects series, for instance, it is shown that the limiting cases of

$$\frac{x}{1}+\frac{x^2}{2}+\frac{x^3}{3}+\ldots\ldots \textit{ad inf.},\ \text{corresponding to } x=1 \text{ and } x=-1,$$

are very different from what Cauchy and other writers affirm them to be. Cauchy says, that when these limits are reached, the series will be divergent in the first case, and convergent in the second: but it is proved in the paper adverted to, that "if x ascend from an inferior numerical value (that is from a fractional value either positive or negative), up to $x=1$ or $x=-1$, the limiting cases will both be convergent, like all the preceding cases; but if the same limits be reached through descending values of the variable, the extreme cases will then, on the contrary, be divergent."

In like manner the limit of the series

$$1+x+2x^2+2.3x^3+2.3.4x^4+\&c.\ \textit{ad inf.}$$

when x arrives at zero, and which is said by Cauchy to be equal to 1, is proved to be in reality equal to a quantity infinitely great.

The errors of Cauchy arise from his neglecting the influence of continuity in these limiting cases: the errors of Poisson, in his researches into the theory of periodic series and definite integrals in the 'Journal de l'Ecole Polytechnique,' and in his 'Théorie de la Chaleur,' are of a directly opposite character: they arise from his arbitrarily introducing continuity where no such principle exists. Poisson admits that periodic series and periodic integrals are in themselves indeterminate; but he considers himself at liberty to overrule this indeterminateness, by introducing into the *series* the ascending powers of a quantity infinitely little different from unity, and by introducing into the *integral* the arbitrary multiplier $e^{-\alpha x}$. By means of this unwarrantable artifice the periodicity is in both cases destroyed: the series is ren-

dered convergent instead of periodic, and the integral is rendered determinate instead of indeterminate.

To avoid the recurrence of these errors, it is proposed to divide infinite series and definite integrals into two classes, those which are dependent upon some condition of continuity, and those which are altogether independent, or *neutral*. Hutton restricted the term *neutral* series to the form $1 - 1 + 1 - 1 +$, &c., because of its being neither convergent nor divergent. It is here proposed to extend the signification of this term, so as to have no especial reference to convergency or divergency: a strictly neutral series may be either convergent, divergent, or periodic.

Some controversy has arisen of late respecting Poisson's theory of definite integrals, and certain forms have been condemned as erroneous which are really correct. Thus the integrals

$$\int_0^\infty \frac{\sin ax}{x}\,dx \text{ and } \int_0^\infty \frac{\cos ax}{1+x^2}\,dx$$

have been recently affirmed to be indeterminate, which they are not. The second of these however has been investigated by Legendre, Gregory and others, by methods altogether objectionable, as is fully shown in the present paper. A correct process for obtaining the proper determinate result, has been given by Sir W. R. Hamilton in his paper on Fluctuating Functions, in the nineteenth volume of the Transactions of the Royal Irish Academy. The ordinary investigations of the first of the preceding forms are correct, although objected to in a paper in the recently published part of the Cambridge Transactions, yet the conclusions obtained by Euler, Fourier, Poisson, and indeed by analysts generally, in reference to this integral, are affected with error: the values of the integral are always stated to be $\frac{\pi}{2}$, 0, $-\frac{\pi}{2}$, according as the constant a is positive, zero, or negative.

It is easily shown however, by a reference to the law of continuity, that the middle one of these values, viz. 0, has no existence; for if x become zero by vanishing *positively*, the value of the integral is still $\frac{\pi}{2}$; and if it become zero by vanishing *negatively*, the value is $-\frac{\pi}{2}$.

Among the collateral topics discussed in the present paper, notice is taken of the method proposed by Deflers, and so often quoted by Poisson, for verifying the well-known integral theorem of Fourier; this method has been properly objected to by Mr. De Morgan, as involving an inadmissible principle: by a little modification, suggested by the theory unfolded in this paper, the defect is removed, and Deflers' short and ingenious proof of Fourier's remarkable theorem rendered conclusive.

The paper terminates with some observations on what is called *discontinuity*, a term which it is thought is often injudiciously and unnecessarily employed in analysis. It is suggested that expressions called discontinuous may generally be contemplated with advantage, as consisting of distinct continuities embraced in a single form. An instance of this is shown in the consideration of definite integrals of the form $\int_{-m}^{n} \frac{dx}{x^p}$, which are treated by Poisson, in the eighteenth cahier of the Journal of the Polytechnic School, but whose conclusions are, by this mode of viewing the integral, shown to be erroneous. The entire paper will probably be published in the Cambridge Transactions.

Letter, on the Deviation of Falling Bodies from the Perpendicular, to Sir John Herschel, *Bart., from* Prof. Oersted.

The first experiments of merit upon this subject were made last century, I think in 1793, by Professor Guglielmini. He found in a great church an opportunity to make bodies fall from a height of 231 feet. As the earth rotates from west to east, each point in or upon her describes an arc proportional to its distance from the axis, and therefore the falling body has from the beginning of the fall a greater tendency towards east than the point of the surface which is perpendicularly below it; thus it must strike a point lying somewhat easterly from the perpendicular. Still, the

difference is so small, that great heights are necessary for giving only a deviation of some tenth-parts of an inch. The experiments of Guglielmini gave indeed such a deviation; but at the same time they gave a deviation to the south, which was not in accordance with the mathematical calculations. De la Place objected to these experiments, that the author had not immediately verified his perpendicular, but only some months afterwards. In the beginning of this century, Dr. Benzenberg undertook new experiments at Hamburg from a height of about 240 feet. The book in which he describes his experiments, contains in an appendix researches and illustrations upon the subject from Gauss and Olbers, to which several abstracts of older researches are added. The paper of Gauss is ill-printed, and therefore difficult to read; but the result is, that the experiments of Benzenberg should give a deviation of 3·95 French lines. The mean of his experiments gave 3·99; but they gave a still greater deviation to the south. Though the experiments here quoted seem to be satisfactory in point of the eastern deviation, I cannot consider them to be so in truth; for it is but right to state that these experiments have considerable discrepancies among themselves, and that their mean therefore cannot be of great value. In some other experiments made afterwards in a deep pit, Dr. Benzenberg obtained only the easterly deviation; but they seem not to deserve more confidence. Greater faith is to be placed in the experiments tried by Professor Reich in a pit of 540 feet at Freiberg. Here the easterly deviation was also found in good agreement with the calculated result; but a considerable southern deviation was observed. I am not sure that I remember the numbers obtained; but I must state that they were means of experiments which differed much among themselves, though not in the same degree as those of Dr. Benzenberg. Professor Reich has published his researches, an abstract of which is to be found in Poggendorff's 'Annalen der Physik.' After all this there can be no doubt that our knowledge upon this subject is imperfect, and that new experiments are to be desired; but these are so expensive, that it is not probable that they would be performed with all means necessary to their perfection without the concurrence of the British Association. I will here state the reasons which seem to recommend such an undertaking. 1. The art of measurement has made great progress in these later times, and is here exercised in great perfection. 2. All kinds of workmanship can be obtained here in the highest perfection. I think it would not be impossible to have an air-tight cylinder of some hundred feet high made for the purpose. This would indeed be expensive, but it would present the advantage that the experiments could be made in the vacuum and in different gases. 3. With these experiments others could be connected upon the celerity of the fall and the resistance opposed to it by the air and by gases. Professor Wheatstone's method for measuring the time would here be of great use. 4. If the southern deviation should be confirmed, experiments could be undertaken in order to discover in how far this could be effected by magnetism in motion. For this purpose balls of different metals might be tried. Very moveable magnetical needles, well-sheltered, but placed sufficiently near to the path of the falling bodies, would indicate magnetical effects induced in them.

On certain Cases of Elliptic Polarization of Light by Reflexion. *By the* Rev. Professor Powell, *V.P.B.A.*

From the principle investigated by Fresnel, that polarized light changes its plane in reflexion, by a certain law dependent on the incidence, for transparent media, and the extension of a similar law to the reflexion from the second surface by Sir D. Brewster (Phil. Trans. 1830), other formulæ were obtained by the last-named philosopher to express the varied phænomena observed by himself (Phil. Trans. 1841), in the reflexion of polarized light from *thin films*, in extension of those previously investigated by Mr. Airy and M. Arago. The whole subject was reduced to the principles of the undulatory theory by Dr. Lloyd (Brit. Assoc. 1841, Sect. Proc. p. 26), who pointed out the further theoretical result, that owing to the difference of phase or retardation, thus produced in the two portions into which the reflected light is divided, polarized light reflected by a thin plate will in general become elliptically polarized*.

* This deduction, though stated in the report given in the Athenæum, is omitted in the volume of the Association.

It is certain however that in a great number of cases of thin plates examined by the author of this communication no ellipticity can be detected. Glass superficially decomposed and giving brilliant tints produces no ellipticity, except in those instances where it has a decided metallic lustre. Vapour condensed on soaped glass (in the manner described by Sir D. Brewster), oils of turpentine, cassia, &c. between glass plates (the upper being slightly prismatic to separate the reflexions), are equally devoid of any indication of ellipticity.

The theory therefore clearly needs some further modification to express the conditions under which the effect may be sensible.

There are doubtless many cases of thin plates in which elliptic polarization is produced (as in the films formed by Nobili's process and by heat, as investigated by the author of this communication, or again, as in mica which has become laminated, &c.), but in these cases the *modus operandi* is well understood; the former arising from the enormous refractive power, in the latter from the crystalline structure.

In the instance of China ink observed by the author, the ellipticity appears equally, whether it be in the form of a film or in a solid mass; but it is only seen in the purest specimens.

In the numerous other cases examined by Mr. Dale it does not appear that anything like films can be supposed; the only condition seems to be the high refractive power.

It may still be a question, then, whether the theory proposed independently by M. Cauchy and by Mr. Tovey be not more easily applicable; since it requires nothing but the very simple and admissible hypothesis, that *the molecules of æther*, for a minute depth within the surface, are *unsymmetrically distributed**.

In various substances containing but a very small proportion of metal, ellipticity has been detected, in addition to those enumerated by the author on a former occasion. Among these are prussian blue, and a specimen of the meteorite from the Cape of Good Hope, 1839, which contains only about 33 per cent. of protoxide of iron, very small portions of oxides of nickel and chrome, and a minute trace of metallic iron†.

On the Bands formed by partial Interception of the Prismatic Spectrum. *By the* Rev. Professor POWELL, *V.P.B.A.*

In the discussion‡ relative to these bands one or two points suggested themselves which appear to need further remark.

The principal objection was, that according to the theoretical formula, a *contraction* of the aperture of the eye or telescope should produce an *enlargement* of the intervals between the bands, which is not confirmed by experiment.

The author finds that with a contraction down to the twentieth of an inch, though there is no sensible enlargement of the intervals, yet *the bands become greatly more vivid and distinct*, while they extend only over a smaller portion of the spectrum at a time§.

With the same plate, the enlargement of the intervals appears to depend solely on the increase in the angular extent of the spectrum subtended at the eye, whether produced by a greater distance from the origin, a greater prismatic angle, higher dispersion, or greater power in the telescope.

The formula involves the ratio of the semi-aperture to the distance of an assumed point on the retina from the geometrical image of the point of light; and this "diffusion" being no arbitrary supposition, but a direct portion of the theory, it seems unreasonable to pronounce it "untenable" and "quite inadmissible," when the question at issue is, whether the theory as a whole will apply to the phænomena.

Apart from all theory, when under certain conditions bands are formed equally whether the plates be applied at one end of the spectrum or at the other, "polarity" seems an improper term by which to describe the effect.

* See the author's Treatise on the Undulatory Theory, &c., p. 33.

† See Phil. Trans. 1839, i. 86.

‡ See Brit. Assoc. 1845, Sectional Proceedings, p. 7.

§ Both these results have since been shown to be in perfect accordance with theory by Mr. Airy.—Phil. Mag. Nov. 1846.

On attempts to explain the apparent projection of a Star on the Moon. *By the* Rev. Professor POWELL, *V.P.B.A.*

Some remarks having been brought forward at the last meeting* relative to the singular phænomenon above named, in which "diffraction" was referred to as at least in a general sense likely to afford an explanation, the author of this communication conceived that some observations he has made might have a bearing on the question.

"Diffraction" has often been appealed to in cases apparently of the same class, but in the more strict and limited sense of the term it cannot apply, since both the conditions and the resulting phænomena appear essentially different.

The phænomena properly ascribed to "diffraction" exhibit *fringes*, and suppose the edge of the intercepting body to be *within* the area of the rays.

But there are some effects of a concomitant kind which have been less attended to. One of the most remarkable of these is that described by Newton (Opt. bk. iii. pt. 1. obs. 5, 6, 7), in which the light admitted through a hole a quarter of an inch in diameter, falling on the edge of an opake body, besides the phænomena since called "diffraction," gave rise to long streaks or "trains" of light darting into the shadow perpendicular to the edge and shown on a *screen*; or, when the *eye* was substituted, producing a *luminous line* running along the edge, between it and the first fringe.

The author has repeated this experiment in a different manner, and though in the original experiment the edge is within the area of the rays, yet a part of the same phænomenon (viz. the line of light along the edge) is seen, even when the edge is *beyond* the rays, by the naked eye, or with a telescope.

When the origin of light is reduced to a mere point (as by using the sun's rays reflected from a very small globule of mercury) and the rays are *wholly* intercepted by a small circular opake disc at the distance of about 2 inches, so that both the luminous point and the disc may be seen at once in focus by a small telescope about 12 feet distant, the bright line is reduced to a luminous patch on the edge of the disc at the part nearest the luminous point which appeared to extend to a small distance *inwards*, and then the rays converging crossed and diverged again faintly. This might possibly be regarded as affording some experimental imitation of the case of the star: the origin is not an absolute point; but if it were, the patch of light *on* the disc might appear like a projection of its image.

Another explanation has been proposed of the phænomenon of projection, on the principle that owing to *aberration*, the star being seen out of its true place, a screen placed in its *true* direction, as the moon, would exhibit the star projected on its disc (Royal Astron. Soc. Reports, vol. vi. p. 246); and taking into account the proper motions of the stars, this would explain the appearance of the phænomenon in one instance and not in another, on the supposition that those proper motions are in opposite directions in the two instances. But this will not apply in the very instance to which reference has been made, of the two stars 119 and 120 Tauri, which have proper motions both in the *same* direction; also, the *principle* of this explanation is rendered questionable altogether from what has been lately suggested by Prof. Challis on the theory of aberration.

The whole subject is perhaps not yet ripe for explanation, since the first astronomers are so much at variance as to the facts, the appearance having been frequently seen by one observer and not by another; while it is believed by some to occur or not, according as the attention is directed to the moon or to the star; which, if true, would seem to point to some ocular cause. Hence a further accumulation of instances is much wanted, any statements of which the author of this paper would be thankful to receive addressed to him at Oxford.

On Elliptic Polarization. *By* Mr. DALE.

The paper which I have to read to the Section relates to some new observed facts in the subject of elliptic polarization, which appear to point out the physical element on which depends the different action of metals on light, as compared with transparent substances in general. They have already been communicated to the Ashmolean Society at Oxford, but I have been induced to bring them forward at present, with a

* Brit. Assoc. Report, 1845, Sect. Proc. p. 5.

view of more readily gaining for them the notice of those interested in optics. This peculiar action, it will be remembered, is of this kind: first, that the metals (and metallic sulphurets, &c.) have no angle of complete polarization for common light; and secondly, that a plane polarized ray becomes elliptically polarized after reflexion from their surfaces, whereas it remains plane polarized after reflexion from glass and such like bodies. Endeavours have naturally been made to account for these phænomena on the principles of the undulatory theory; and always, apparently, on the supposition that the laws of reflexion from transparent (uncrystallized) bodies were already rigorously given by Fresnel's formulæ, but that a new and distinct theory was required for metallic reflexion: thus assuming that the two classes of phænomena were abruptly separated, without any intermediate links of connexion. It has, indeed, long been known that several transparent or translucent substances have no angle of complete polarization. Thus Biot (Traité de Physique, iv. 288) has excepted sulphur and the diamond; and Sir John Herschel (Optics, Art. 845; see also 831) excludes from the general rule, besides the metals, those substances which have the adamantine lustre; which term is applied, in Mohs's system of crystallography, to several of the minerals to be presently spoken of, as resembling the metals in another respect. I do not know that any writer, except Mr. Green (in Camb. Phil. Trans. vol. vi.), has stated this exemption to be general for all substances having a high refractive index; but it is important to recall this experimental fact to our attention, on account of its coincidence and harmony with the new result which I have now to state. It consists in this: that these same highly refractive substances resemble the metals also in a second respect—that they confer elliptic polarization on a plane polarized ray reflected from them. The following list of substances, in which this property was observed, will be found to contain most of those at the top of Sir D. Brewster's list of refractive indices:—

Indigo—which is remarkable for possessing the metallic lustre without containing any metal.
Artificial realgar.
Diamond—of which three specimens were tried.
Sulphuret of zinc in transparent crystals.
Glass of antimony—translucent.
Sulphur—melted on a polished slip of zinc foil.
Tungstate of lime—transparent.
Carbonate of lead in crystals, clear and limpid as glass.
Hyacinth, or zincon—translucent.
Arsenious acid.
{ Garnet.
{ Idocrase.
Helvine.
Labrador hornblend.

Of which the last five possess the property in a very slight degree only. The test used in every case was the dislocation of the rings of a plate of calc spar; of which a very good specimen was used, capable of exhibiting eight or nine red rings: and all the experiments were made by candle-light, which is indispensable. It will secure greater confidence in these results to say, that all the specimens which I submitted to Prof. Powell's examination, in a different instrument, were found by him to produce the above effect; and from his published observations several more cases may be quoted in confirmation of the general result: such are—chromate of lead, litharge, plumbago, and Indian ink. The natural conclusion from these facts appears to be, that in a perfect mathematical theory of reflexion, both cases should be embraced in one set of formulæ, of which some terms or coefficients should be insensibly small, except when the refractive index was very large; that, *strictly* speaking, no substances *completely* polarize common light at any angle, but that the residue of unaltered light is too feeble to affect the eye, when the refractive index is below a certain limit; and that plane polarized light always becomes elliptically polarized, but that the virtual difference of paths of the two compact vibrations parallel and perpendicular to plane reflexions is insensibly small, except the refractive index surpass a certain value greater than the refractive indices of felspar and sapphire, which I found to produce no dislocation of the rings. It is remarkable, that such formulæ have some time

since been deduced from a very profound mathematical investigation by Mr. Green, in the Cambridge Philosophical Transactions, vol. vii.—whose results, however, do not seem to have met with much attention. Now, however, that they have met with the above undesigned general confirmation, it seems very desirable that they should be compared with the numerical results of experiments of Sir D. Brewster and Prof. Powell. Mr. Green adopts, as part of the basis of his calculation, the original view of Fresnel,—that the vibrations of a polarized ray are perpendicular to the plane of polarization; but as this point is a matter of dispute amongst mathematicians, I have thought of an experimental method by which this point might, as I think, be decided, independently of all theory. It consists in the observation of the shifting of the fringes produced by two pencils of light polarized in the same plane on interposing in their paths a piece of compressed glass. This last apparatus is to be constructed in the following manner:—A strip of clear plate, 4 or 5 inches long by half an inch broad, is to be provided; and its narrowest faces (or narrowest long sides of the parallelopiped) are to be carefully polished, and rendered perfectly plane and parallel to each other,—at least, in the middle part of their length, through which the light is to pass. And the glass must be so well annealed and so free from striæ as to allow of the formation of fringes by interfering pencils which have traversed it. It is to be provided with a wooden frame and screw, capable of compressing it in the middle. [A similar apparatus has already been employed by Brewster, Ling, and Pouillet, to show that glass under pressure possesses double refraction.] We may now proceed to the experiment itself. Let us suppose, then, that the arrangements have been made in a darkened room for producing the interference of two pencils of light, which are to be polarized in the same plane, by passing, for example, through the same tourmaline plate. This arrangement might, in fact, be that of Fresnel, in which a slender beam is reflected from two glass plates very slightly inclined, provided that the light were incident at the polarizing angle of glass. And, for the sake of clearness, let us suppose the two foci, or virtual foci, to be vertically one above the other, the plane of polarization to be vertical, and the glass to be interposed with its length horizontal. Then, in its natural state, it will produce no displacement of the fringes, if made carefully after the above description. But let us consider what will be its effect if interposed in its bent state. The elasticities on its convex and concave sides are different in this respect, that the particles are dilated or compressed *parallel to the length of the glass*; whereas little or no alteration of elasticity is produced in a plane perpendicular to the length of the glass. Hence if the vibrations of the two polarized pencils are really executed perpendicularly to the plane of polarization, or parallel to the length of the glass (according to the arrangement above agreed upon), they will be propagated with different velocities, and the fringes will be displaced parallel to the length of the glass, in a direction which might be inferred from some statements of Sir D. Brewster, but which is quite unimportant to the present purpose. If, however, on the other hand, the vibrations be executed in the plane of polarization, or perpendicular to the length of the glass, the two rays will traverse the glass with almost, or quite the same velocities, and the fringes will either not be displaced at all, or to a far less amount than in the preceding case.

Notice of a New Property of Light exhibited in the Action of Chrysammate of Potash upon Common and Polarized Light. By Sir DAVID BREWSTER, *K.H., F.R.S.*

The Chrysammate of Potash, which crystallizes in very small, flat rhombic plates, has the metallic lustre of gold, whence it derives its name of golden sand. When the sun's light is transmitted through the rhombic plates it has a reddish yellow colour, and is wholly polarized in one plane. When the crystals are pressed with the blade of a knife on a piece of glass, they can be spread out like an amalgam. The light, transmitted through the thinnest films thus produced, consists of two oppositely polarized pencils,—the one of a bright carmine red and the other of a pale yellow colour. With thicker films, the two pencils approach to two equally bright carmine red pencils. It is to the reflected light, however, and its new properties, that I wish to direct the attention of the Section. Common light, reflected at a perpendicular incidence from the surfaces of the crystals, or of the films, has the colour of virgin gold. It grows less and less yellow as the incidence increases, till it becomes of a pale bluish

colour at very great incidences. The compound pencil, thus reflected and coloured, consists of two oppositely polarized pencils,—one polarized in the plane of reflexion, and of a pale bluish white colour at all incidences; and the other polarized perpendicular to the plane of reflexion, and of a golden yellow colour at small incidences, passing successively into a deeper yellow, greenish yellow, green, greenish blue, blue, and light pink, as the angle of incidence increases. This very remarkable property, which I have discovered also in some other crystals, is not caused by any film of oxide formed upon the natural surface of the crystal, nor is it the result of any change produced upon the surface by external causes. It is exhibited, under the usual modifications, if the surface of the chrysammate is in optical contact with fluids, and, by pressure, with glass:—and when the crystal is in the act of being dissolved, or when a fresh surface is exposed by mechanical means, the superficial action of the crystal upon light is in both cases the same. When the chrysammate is re-crystallized from an aqueous solution, it appears in tufts of prisms of a bright red colour, the golden reflexion being overpowered by the transmitted light; but when these tufts are spread into a film by pressure, the golden yellow colour reappears. When the crystals of chrysammate are heated with a spirit lamp, or above a gas burner, they *explode* with a flame and smoke like gunpowder; and, by continuing the heat, the residue melts and a crop of colourless amorphous crystals is left. I have found the same explosive property in the Aloetinate of Potash.

Description of a Portable Equatorial Stand for Telescopes without Polar Axis. By Richard Greene, *M.D.*

All previous attempts to produce equatorial motion have (the author believes) been based upon the notion that the telescope should revolve upon a material axis, which of course must be adjusted parallel to the axis of the earth. The principle also is bad, inasmuch as the telescope is supported near the centre, and the moving power is applied to that point, instead of the extremity of the tube.

In following any of the heavenly bodies either to the east or west of the meridian with the common stands mounted with altitude and azimuth movements, the observer is obliged to keep them both continually in action to prevent the object getting out of the field of the telescope. As the effect of these two powers acting at right angles to each other is to cause the tube to move in the diagonal between them, it occurred to the author that it would be more simple and equally efficacious to employ only one moving power in the direction of that diagonal, and thus obtain the same motion by one screw, which before was obtained by the two screws worked together. He also remarked that when the object is passing the meridian, for a certain time it will remain in the field of view by moving the azimuth screw *alone*.

The essential principle of the invention is simply to be able to place the horizontal or azimuth screw in all situations of the heavenly bodies in a position similar to that in which it is placed when an object is passing the meridian, viz. parallel to a tangent of the circle the body is describing and touching the circle at the point where the body then is. The common azimuth screw fully answers the purpose when the body is on the meridian, as the tangent is then horizontal. When the body observed is to the east of the meridian, as it is then rising higher every instant, and at the same time moving westward, all that is required is to point the adjustible screw, which the author calls the *equatorial screw*, upwards from the observer to such an angle as appears to be parallel to the path the body is describing, which, from its altitude and distance from the meridian, can be pretty nearly guessed by an astronomer. If he has elevated the screw to the proper angle, the body will remain very nearly in the centre of the field of view during the time he is following it through the length of the screw. If, however, it appears to sink in field, it shows that the screw is not sufficiently elevated, and that it rises faster than the axis of the telescope, and he must raise the remote end of the screw a little more: if the star rises in the field, of course it shows that the screw is too much elevated. By two or three trials the angle may be found in less than a minute. If the body viewed be to the west of the meridian, the remote end of the equatorial screw is of course to be depressed, pointing downwards from the observer.

The principle of this equatorial movement is easily applied to many of the stands now in general use, as well as to the Herschel stand, on which the author first tried it.

Having no stands of his own, except the Herschel stand, (and this certainly defective in stability, in consequence of the great mirror being unsupported except by the tube, upon which it acts through a long and powerful lever of agitation,) Dr. Greene turned his attention to the construction of some simple stand based upon the principle of stability which the triangle affords, and presented a model of his first attempt to attain that object.

In this arrangement the heel of the telescope hangs by two pivots upon two Ys fixed to the upper surface of a flat circular disc, which revolves upon another similar disc, by means of a pin in the centre; the lower disc stands upon three very low feet to ensure its stability. The upper or eye-end of the telescope is attached by a pin to an *equatorial slide*. The pin is united to a slide which moves parallel to the tube of the telescope at its under side, and being moved by a rack and pinion, gives the slow elevation movement. The *equatorial slide* is supported by a pair of shears, capable of being lengthened or shortened at pleasure, to effect the quick motion in altitude. The legs of the shears rest upon the two extremities of a sliding piece moving by rack and pinion in the groove of a piece of mahogany or other hard wood in the shape of the letter T, supported by three very low feet to ensure its steadiness. The sliding piece is moved by a long handle attached to the pinion, and gives the slow azimuth motion to the entire stand. To unite the different parts into one system, the piece which supports the shears, and the lower circular disc which supports the heel of the telescope, are attached by two bars with hooks at each extremity, the bars being themselves bound together by two diagonal braces.

It will be seen at a glance, that the telescope and its stand form one great triangle, while each of its parts is a minor triangle; that the great mirror is solidly supported, having no tendency to disturb any part of the fabric by its disposition to be moved by any slight external force.

On an easy Method of contracting the Aperture of a Large Telescope.

By HENRY LAWSON, *F.R.S., F.R.A.S., &c.*

It is well known to the practical astronomer, that in using a telescope of large diameter it is needful to contract the aperture of the object-glass when measuring binary stars, &c., and also when the haziness of the atmosphere demands such contraction. The mode adopted is the adaptation of a brass tube, 6 to 12 inches long, to the eye-end of the telescope tube, in such a manner that it may slide out and in with facility. Into one end of this tube the eye-pieces of the telescope must screw (or what is better, slide). Within this tube is to be placed a moveable diaphragm, made to slide up and down the tube by means of a slit and stud. The diaphragm is to be pierced with an aperture of such size as just to let the *whole cone* of rays proceeding from the object-glass pass through it towards the eye-glasses, when the diaphragm is drawn down or stands near to the eye-piece. When the aperture of the object-glass is required to be contracted, the diaphragm must be slid towards the object-glass, and it will have the effect of circumscribing the cone of rays to any required diameter. The benefits resulting from the above-described plan are the following: that the astronomer can with the greatest facility and without moving from the eye-end of his telescope, adjust or contract the aperture of the object-glass to any required diameter; he can vary the magnifying power without shifting or deranging the aperture; and, lastly, he can produce these benefits without fear of altering the adjustments, or turning the telescope from the object in view.

On the Arrangement of a Solar Eye-piece.

By HENRY LAWSON, *F.R.S., F.R.A.S., &c.*

This arrangement does away with the inconvenient and dangerous breaking of the *dark glass* when viewing the sun through telescopes of large size, and enables the astronomer to view the sun with the *whole aperture* of his telescope, however large it may be; thus giving an immense advantage when scrutinizing the wonderful and most interesting appearances of the solar disc. The method consists in placing the dark-glass or glasses *within* the telescope, by means of a brass tube supported between the object-glass and the eye-glass of the telescope, the tube being from 3 to 18 inches (according to the length of the telescope), measured from the eye-piece, to which

it is to be attached. By this means the cone of rays proceeding from the object-glass towards the eye-glass is intercepted by the dark glass at a considerable distance from its focus, or most heating point, and thus the heating power of the rays, being spread over a large surface of the dark glasses, passes through without injuriously heating them, and enters the eye in a cool and agreeable temperature. Another benefit derived by this arrangement is, that the cell holding the dark glass may be made to contain several glasses; and those may be of different colours; whereby an opportunity is afforded of repeating the valuable experiments of Sir John Herschel on transmitted light through different coloured media; and also attempering or adjusting the intensity of the light entering the eye to the sensibility of the retina. Another benefit is obtained, that of using various magnifying powers with the *same* dark glass arrangement with the greatest facility.

On the Meteorological Observations at Kew, with an Account of the Photographic Self-registering Apparatus. *By* F. RONALDS, *F.R.S.*

Mr. Ronalds, on presenting his third annual volume of observations and experiments made at the Kew Observatory, described his experiments on the photographic self-registration of the electrometer, the barometer, the thermometer and the declination magnetometer; explained his existing apparatus for these purposes, and exhibited the resulting photographs, but first briefly adverted to his previous proposals in 1840 and 1841, and experiments in 1844, relative to the subject. The principal characteristic of his improved system is a peculiar adaptation of the *lucernal microscope*. An instrument of this kind was employed in July 1845 to register the variations of Volta's *atmospheric electrometer*. The pair of straws were properly insulated and suspended within the body of the microscope and towards its object-end. A condensing lens was placed at the end itself, and a good lamp stood beyond it. A strong light was therefore projected upon those sides of the straws which were turned towards the condensing lens, and the other sides were in deep shade. The light also impinged upon a little screen fitted into the back of a case about two feet long, fixed to the eye-end of the microscope at right angles with it, and vertically. Through this screen was cut a narrow curved slit whose chord was horizontal and radius equal to the length of the straws. Between the electrometer and the screen a combination of achromatic lenses by Ross was adjusted to produce a good chemical focus of the electrometer, at a distance as much beyond the external surface of the screen as the thickness of one of the plates of glass to be presently mentioned. In the long vertical case was suspended a frame about half the length of the case, provided with a rabbet, into which two pieces of plate glass could be dropped, and these brought into close contact by means of six little bolts and nuts. The frame could be removed at pleasure from the line by which it was suspended, and the line, after passing through a small hole stopped with grease at the top of the long case, was attached to a pulley about four inches in diameter on the hour arbor of a clock. Lastly, counterpoises, rollers and springs were used for ensuring accurate sliding of the frame, &c. A piece of Mr. Collen's photographic paper was now placed between the two plates of glass in the moveable frame; the long case was closed so as to prevent the possibility of daylight entering it, the clock was started, and the time of starting was noted. All that part of the paper which was made to pass over the slit in the screen by the motion of the clock, became now therefore successively exposed to a strong light, and was consequently brought into a state which fitted it to receive a dark colour on being again washed with the usual solution, excepting those small portions upon which dark images of the lower parts of the straws were projected through the slit. These parts of course retained the light colour and formed the long curved lines or bands, whose distances from each other, at any given part of the photograph, i. e. at any given time, indicated the electro-tension at that time. Sometimes daylight was used instead of the light from a lamp, and in that case, during the process, some appearances of the sky were occasionally noted, by which it was evident that in serene weather, when the sun's light and heat varied, and the paper became consequently either more or less darkened, the electric tension, as shown in the photograph, varied also, increasing with the increase of light, &c. This fact has not perhaps been before observed, but as the darkening effect on the paper could not be always depended upon, separate notes were taken of the intensities of light and the same results obtained. At the suggestion of

the Astronomer Royal, a *distinguishing electrometer*, formed on the dry pile system, was afterwards employed, which exhibited in the photograph, not only the tension, but the kind of electricity possessed by the electrometer at any given time. The *dry thermometer* was next tried. It was of the horizontal kind, had a flat bore, and its tube was introduced through the side of the microscope. The tube had a diaphragm of very narrow aperture fixed upon it, and the slit in the screen, at the eye-end of the microscope, was now of course straight and horizontal. The image was a little magnified, and the breadth of the dark band or line in the photograph became the measure of temperature inversely at any given time*. The *barometer* employed was of the siphon kind. The microscope was turned in order to bring the long case and its sliding frame into a horizontal position. The clock was placed at one end, and a little weight, sufficient to keep the frame steady, was suspended by a line passing over a pulley at the other. The lower leg of the barometer was introduced through the now bottom of the microscope; it was provided with a similar kind of diaphragm to that on the thermometer, and of course the slit in the screen was now vertical. A light blackened pith-ball rested on the surface of the mercury, and its image was slightly magnified, but will in future be much more so. The *declination magnet* was one of two feet, lent to Mr. Ronalds by the Astronomer Royal. It was provided with a damper, and its mode of suspension was essentially similar to that of the Greenwich declinometer. In order to adapt it for self-registration, a light conical brass tube, projecting six inches beyond its north end, was affixed to the lower side of the spur which carried it, and to the north end of that tube a small wire, called the index, was attached at right angles. This index descended through little slits in the bottoms of the two cases which enclosed the magnetic, and took the place of the electrometer in the lucernal microscope, which was placed below the cases, and was now required to be much longer than before, in order that the image and motion might be sufficiently magnified, yet a flat field retained. Everything was firmly fixed upon the two pillars which formerly carried the transit instrument of His Majesty George III. A great many photographs were obtained and sent for inspection to Greenwich. Concerning some term-day impressions, Mr. Glaisher, the Magnetical and Meteorological Superintendent of the Greenwich Observatory, says, in an official note, that "the beautiful agreement of the results with these at Greenwich is highly satisfactory."

On some Meteorological Phænomena. *By* Professor WARTMANN.

Although many attempts have been made of late to extend our knowledge of the electrical phænomena of the atmosphere, it must be confessed that much remains to be done. The frequency of the flashes of lightning, according to the latitude to the seasons, is a subject of inquiry which has been recommended by M. Arago. It would also be interesting to record the duration of thunder-storms, the number of flashes of each of the three classes which have appeared, the height and general appearance of the clouds, and the hygrometric state of the atmosphere.

I shall take the liberty to point out some facts which I had occasion to witness on the evening of the 1st of August last. After many hot days, clouds appeared on the south-west part of the horizon of Lausanne, and when over the town they began to become illuminated almost without interruption. I counted more than forty flashes in twenty-two minutes, two-fifths of which were of the first class, and all going eastward.

A flash, of such a white brilliancy that the eye could not bear it, but the appearance of which was perfectly definite, did *not* disappear suddenly, but left a florescent trace of a dark red colour, like to the illusions of the dissolving views and the *trainées* or trails of certain shooting stars which I observed on the night of the 10th of August 1838.

Another flash of the first class appeared at the under part of the clouds, and after a rather long course, it vanished at the very edge of it: no thunder was heard. Two flashes were bicuspidated; three others were tricuspidated at some distance from their origin, two of which appeared together, one over the other, in the same hori-

* In order to convert this into the wet bulb *hygrometer*, nothing of course is necessary but the application of the usual cup of water and the capillary threads.

zontal position. Are those flashes as scarce as it is generally believed? Are they produced by a particular state of humidity which makes the state of the air better conductors in many given directions simultaneously than in others? This I am not able to decide; but I think that the quantity of rain which happens to fall during a thunder-storm has a great influence upon the falling of the electric fluid. Indeed, in a recent instance, a thunderbolt fell in a low part of a vintage near Lausanne, burning all the stems on an area of more than eighty feet square, during a shower of the most tremendous character, and without being attracted by more elevated conductors which were at a short distance; and, on the contrary, two years ago, during a storm which was accompanied by no rain, the thunder fell on a neighbouring situation, and burned by ricochets, stems here and there, upon a surface of more than four acres.

Dr. Lee presented the following tables to the Section:—

1. Meteorological Observations for the year 1845, made by J. R. Crowe, Esq., the British Consul-General of Norway, residing at Christiana. These tables are a continuation of others made in 1843, and presented to the British Association at York, and of similar tables made in 1844, and presented to the Association at Cambridge, and which are noticed in the volume of the Proceedings for 1845, at page 19 of the abstracts of communications to the Section of Mathematics and Physics. They consist of observations of the barometer and thermometer, and of the direction of the wind, made on nearly every day in the year 1845, at the hours—7 A.M., 9 A.M., 2 P.M., 4 P.M., and 10 P.M., with the means of each column for each month, and the mean temperature of each month. The depth of snow is given for the months of January, February and March, in cubic inches; and the quantity of rain in cubic inches for each of the other months of the year.

2. Meteorological Observations made at Alten in West Finmark, at the Kaafjord Meteorological Observatory, in the years 1844 and 1845, by J. F. Cole, Esq. and J. H. Grewe, Esq., of the Alten Mining Company. These tables are a continuation of others for the year 1843, presented to the British Association at York, and which have been deemed worthy of notice by Colonel Sabine, who has referred to them in a note on his paper on the Meteorology of Bombay, at p. 80 of the Report of the Proceedings at Cambridge, in the volume published in 1845. These tables contain the height of the barometer and thermometer, in shade, at 9 A.M., 3 P.M., and 9 P.M., with the maxima and minima of the thermometer at 3 P.M.; the quantity of rain or melted snow; the force and direction of the wind, and of the clouds, and the description of clouds, and the proportion of clear sky at the same hours. To which are added, tables of the half-hourly results of all the above observations on the 21st and 22nd of each month in the year.

3. Observations on the Aurora Borealis during the year 1845, made at the Kaafjord Meteorological Observatory at the Alten Copper Works, by J. F. Cole, Esq. and J. H. Grewe, Esq. These tables contain observations upon the position and the degree of intensity, and the forms of the aurora, which have been made by these zealous amateurs of meteorology during the months of January, February, March and April, September, October, November and December; no observations being practicable during the summer months, on account of the brightness of the daylight during this portion of the year.

On a New Anemometer. *By* Dr. Banks.

The instrument is worked by a vane supported on a hollow wooden shaft about two inches diameter and three feet long, whose upper end is supported by slight friction rollers, and the bottom rests on a steel point.

Each of two levers holds a pencil, one for the direction of the wind, working in a spiral of three turns, which by a very simple contrivance returns to its position if the wind moves round the compass with frequency. The other lever is acted upon by the force-board attached to the vane, and which, in its retirement from an increasing wind, raises a series of weights together with a disc, upon which, by a roller, the lever rests. The instrument is about 2½ feet long by 2 feet high, exclusive of the vane, which is attached to a tin tube of length according to circumstances.

Meteorological Observations. *By* Capt. W. W. CHILDERS.

TABLE A.—Meteorological Observations, Saint Helier, Jersey, deduced from Hourly Observations taken by William Walbanke Childers, late Captain in the 42nd Royal Highlanders, assisted by Mr. John B. Le Roy, Optician; from the Mean of four barometers and three thermometers. The extremes noted by a perpendicular Self-Registering Thermometer eighty-five feet above the mean level of the sea. Soil gravelly clay. Latitude 49° 11′ N., Longitude 2° 06′ W.

	Height of Thermometer									Daily prevailing Wind.										Barometer.			
	9	2	5	8	11	Nt.	Aver.	Highest.	Lowest.	Mean.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Var.	Calm.	Total.	Aver.	Highest.	Lowest.	Mean.
1844.	°	°	°	°	°	°	°	°	°	°												inches.	inches.	inches.	inches.
Nov.	49	52	50	49	48	45	49·0	59	32	45·5	4	2	8	2	4	5	3	..	..	2	30	29·65	30·15	28·30	29·40
Dec.	39	41	40	39	39	36	39·0	49	24	36·5	4	15	4	5	..	..	..	..	..	3	31	29·65	30·05	28·65	29·35
1845.																									
Jan.	42	44	42	41	41	39	41·5	49	32	40·5	3	3	3	5	1	7	3	3	1	2	31	29·55	30·00	28·60	29·30
Feb.	38	41	38	38	38	35	38·5	49	26	37·5	2	12	1	2	1	2	..	4	2	2	28	29·60	30·25	29·35	29·80
Mar.	39	42	39	38	36	35	38·0	55	25	40·0	5	12	..	..	2	3	2	1	5	1	31	29·65	30·35	29·05	29·70
April	49	55	51	48	46	44	49·0	65	39	52·0	1	12	..	4	..	4	4	3	2	..	30	29·45	29·90	28·65	29·25
May	53	58	54	50	49	46	51·7	70	41	56·0	5	6	..	1	1	4	2	8	4	..	31	29·70	30·30	29·25	29·75
June	62	66	63	59	56	54	60·0	77	40	58·5	2	6	1	2	1	4	8	5	1	..	30	29·90	30·45	29·30	29·90
July	62	67	64	59	57	55	61·0	79	48	63·5	..	..	..	6	5	..	10	4	4	2	..	31	29·70	29·90	29·30	29·60
Aug.	61	65	62	58	56	54	59·5	69	43	56·0	3	2	1	2	..	4	11	8	..	..	31	29·70	30·20	28·90	29·55
Sept.	59	63	59	56	55	53	58·0	72	44	58·0	..	11	1	2	..	8	5	2	1	..	30	29·60	30·00	29·00	29·50
Oct.	55	58	54	52	51	49	53·5	68	41	54·5	2	6	1	7	1	3	5	3	1	2	31	29·90	30·35	29·05	29·70
Aver.	51	54	51	49	48	45	50·0	79	24	51·5	31	87	26	37	11	54	47	41	19	12	365	29·65	30·45	28·30	29·35
Nov.	50	54	51	49	48	46	49·5	58	37	47·5	..	4	..	10	1	9	4	2	..	..	30	29·40	29·95	28·60	29·30
Dec.	46	49	47	46	45	43	46·0	56	31	43·5	1	1	..	2	..	16	5	5	..	1	31	29·80	30·35	28·55	29·45
1846.																									
Jan.	45	49	45	45	44	43	45·0	54	32	43·0	..	..	..	7	..	13	5	1	..	5	31	29·60	30·60	28·90	29·75
Feb.	46	48	46	45	44	43	45·0	57	31	44·0	2	5	1	8	..	3	3	5	..	1	28	29·80	30·15	29·20	29·70
Mar.	46	50	47	45	44	42	45·5	54	32	43·0	2	3	..	7	..	16	..	3	..	..	31	29·60	30·55	28·85	29·70
April	50	53	51	48	47	44	49·0	59	34	46·5	2	5	..	9	..	5	2	7	..	..	30	29·45	30·25	28·70	29·45

TABLE B.—Meteorological Observations, Saint Helier, Jersey, taken by Captain William Walbanke Childers, for the year 1846, with a Comparative Table of the difference in Temperature between that place and the Horticultural Gardens at Chiswick, as reported in the Gardeners' Chronicle. St. Helier, 49° 11′ N. Chiswick Gardens, 51° 20′ N.

	Thermometrical Observations.									Direction of Wind.										Comparative Table.					
																				Chiswick			Difference between Jersey & Chiswick.		
	9	2	5	8	11	Nt.	Aver.	Highest.	Lowest.	Mean.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Var.	Calm.	Total.	Highest.	Lowest.	Mean.	Highest.	Lowest.	Mean.
1846.	°	°	°	°	°	°	°	°	°	°												°	°	°	°	°	°
Jan.	45	49	45	45	44	43	45·0	54	32	43·0	..	..	..	7	..	13	5	1	..	5	31	56	21	44·3	− 2	+11	+0·7
Feb.	46	48	46	45	44	43	45·0	57	31	44·0	2	5	1	8	..	3	3	5	..	1	28	64	24	40·2	− 7	+ 8	+4·8
Mar.	46	50	47	45	44	42	45·5	54	32	43·0	2	3	..	7	..	16	..	3	..	..	31	62	20	43·4	− 8	+12	+2·1
Apr.	50	53	51	48	47	44	49·0	59	34	46·5	2	5	..	9	..	5	2	7	..	..	30	65	29	47·8	6	+ 5	+1·2
May	Being from home, the observations were neglected.										..	13	2	5	..	8	2	1	..	..	31	81	34	52·3			
June	68	73	70	68	65	63	68·0	80	57	68·5	..	15	..	2	..	10	..	..	2	1	30	93	43	70·0	−13	+14	−2·0
July	66	69	68	65	62	59	65·0	81	49	65·0	..	..	4	5	..	17	3	..	2	..	31	92	44	66·4	−11	+ 5	−1·4
Aug.	65	68	66	63	61	59	63·8	79	2	65·5	..	8	1	1	1	10	1	6	2	1	31	92	44	61·6	−13	+ 8	+2·2
Sept.	63	67	64	61	59	58	62·0	74	50	62·0	..	16	..	1	..	3	4	1	3	2	30	78	40	60·0	− 4	+10	+2·0
Oct.	54	57	55	53	52	50	53·8	64	41	52·5	..	4	1	2	1	9	6	3	4	1	31	67	29	49·5	− 3	+12	+3·0
Nov.	47	49	48	46	46	44	46·3	61	31	46·0	..	10	1	7	1	8	..	1	1	1	30	61	16	39·4	± 0	+15	+8·0
Dec.	31	49	39	38	38	35	38·5	50	25	37·5	1	16	..	..	..	5	1	7	1	..	31	44	11	31·0	+ 6	+14	+6·5
Aver.	53	57	55	52	51	49	53·0	81	25	52·5	7	95	10	54	3	107	27	35	15	13	365	93	11	51·6	−12	+14	+1·0

From the above comparative table, it appears that Jersey, although within a comparative short distance of London, enjoys a far more equable temperature, neither undergoing so great a degree of heat nor exposed to so extreme cold. This in a great measure arises from its position, and the great rise and fall of the tide, upwards of forty feet between the levels at high and low water, spring tides and the nature of its soil; a rich loomy clay with gravelly subsoil. In June and July, for instance, the temperature in London reached 93°, in Jersey only 81°; whereas in December the thermometer in London fell to 11°, in Jersey no lower than 25°. Jersey is a very moist climate, S.W. winds having prevailed 107 days during the year, and the quantity of rain fallen being nearly double that at Chiswick.

TABLE C.—Meteorological Observations, Saint Helier, Jersey, for the year 1844, commencing in November 1843, before taking the Observations hourly, by Captain Childers.

	Thermometrical Observations.								Direction of Wind.									Barometer.			
	9	2	5	8	11	Nt.	Aver.	Highest	Lowest.	Mean.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Var.	Calm.	Total.	Aver.	Highest	Lowest.	Mean.
1843.	°	°	°	°	°	°	°	°	°	°												inches.	inches.	inches.	inches.
Nov.	48	52	49	48	47	44	48·4	58	29	43·5	..	5	1	2	1	8	3	4	6	..	30	29·40	30·10	28·80	29·45
Dec.	46	49	47	46	45	43	45·5	53	32	42·5	..	5	2	6	..	4	1	4	3	6	31	30·10	30·30	29·80	30·05
1844.																									
Jan.	45	47	46	46	45	41	45·0	54	31	42·5	3	9	1	3	..	4	1	8	1	1	31	29·00	30·00	28·70	29·35
Feb.	42	44	42	41	41	38	41·5	52	26	39·0	3	6	..	1	1	5	6	5	2	..	29	29·00	29·65	28·15	28·90
Mar.	46	49	47	45	44	40	45·3	62	26	44·0	1	6	5	2	2	5	4	6	..	..	31	29·25	30·10	28·50	29·30
April	54	59	56	51	48	44	51·7	75	36	55·5	4	11	3	1	2	2	3	2	1	1	30	29·70	30·15	29·10	29·60
May	54	57	55	52	49	45	52·5	67	40	53·5	6	20	1	..	..	..	..	3	1	..	31	29·60	29·95	29·30	29·55
June	59	62	61	59	57	53	58·3	71	46	58·5	..	3	4	1	1	14	4	1	2	..	30				
July	63	67	66	63	60	57	62·6	87	53	70·0	1	5	2	5	1	6	5	5	1	..	31	Observations not to be depended upon, being irregularly taken during my absence.			
Aug.	62	67	64	61	59	55	61·3	76	51	63·5	4	5	3	..	1	6	5	3	4	..	31				
Sept.	63	68	67	64	62	57	63·5	79	50	64·5	5	12	6	2	..	2	..	2	1	..	30				
Oct.	56	59	57	55	54	51	55·2	65	40	52·5	1	5	2	2	6	8	1	4	..	1	31	29·10	29·85	28·25	29·05
Aver.	53	57	55	53	51	47	52·6	87	26	54·7	28	92	30	26	15	64	38	47	22	9	366	29·50	30·30	28·15	29·40

TABLE D.—Comparative Temperature Table for the years 1843, 1844, 1845 and 1846, taken by Captain Childers at St. Helier, Jersey, Latitude 49° 11′ N.

	1843.				1844.				1845.				1846.			
	Highest	Lowest.	Mean.	Aver.	Highest	Lowest.	Mean.	Aver.	Highest	Lowest.	Mean.	Aver.	Highest	Lowest.	Mean.	Aver.
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
Jan.	48	34	41·0	41·0	54	31	42·5	45·0	49	32	40·5	41·5	54	32	43·0	45·0
Feb.	51	30	41·5	37·0	52	26	39·0	41·5	49	26	39·0	38·5	57	31	44·0	45·0
March	50	32	46·0	42·0	62	26	44·0	45·3	55	25	40·0	38·0	54	33	43·0	45·
April	58	37	47·5	49·0	75	36	55·5	51·7	65	39	52·0	49·0	59	34	46·5	49·0
May	61	43	52·0	52·0	67	40	53·0	52·5	70	41	55·5	51·5	Not observed.			
June	68	48	58·0	60·0	71	46	58·5	58·3	77	40	60·0	60·0	80	37	58·5	59·0
July	74	56	65·0	63·0	87	53	70·0	62·5	79	48	63·5	61·0	81	49	65·0	65·0
Aug.	81	60	70·5	66·0	76	51	63·5	61·3	69	43	56·0	59·5	79	52	65·5	65·3
Sept.	79	47	63·0	65·0	78	50	64·0	63·5	72	44	58·0	58·0	74	50	62·0	62·0
Oct.	70	30	50·0	56·0	69	40	52·5	55·2	68	41	54·5	53·5	64	41	52·5	53·3
Nov.	58	29	43·5	48·5	59	32	45·5	48·7	58	37	47·5	49·5	61	31	46·0	46·3
Dec.	53	32	43·5	45·5	49	24	36·5	39·0	56	31	43·5	46·0	50	25	37·5	38·5
Aver.	65	40	52·0	52·0	65 5	38 0	52·3	51·3	64	37	51·0	50·5	65	39	52·1	52·7
Differ.	+ 1	+ 1	±0	±0	+ 1 5	− 1 0	+ 0·3	− 0·7	±0	−2	− 1·0	− 1·5	+ 1	± 0	± 0	+ 0·7

TABLE D. (*continued*).

Average.	Highest.	Lowest.	Mean.	Aver.
	° ′	°	°	°
Jan.	51·2	32·2	42·5	43·0
Feb.	52·2	28·2	41·0	40·0
March	58·0	29·0	43·2	42·5
April	64·5	36·5	50·0	46·5
May	69·0	41·0	55·0	52·0
June	74·0	49·0	61·0	62·0
July	78·0	51·5	64·0	63·0
Aug.	76·0	52·5	63·5	63·0
Sept.	76·0	47·0	61·0	62·0
Oct.	68·0	37·0	53·0	55·0
Nov.	67·0	33·0	45·0	48·5
Dec.	63·0	31·0	42·0	44·0
Aver.	64·0	39·0	52·0	52·0

REMARKS.

Hottest day, 23rd July 1844. Ther. 87°.
Coldest day, 5th March 1845. Ther. 25°.

HOTTEST MONTHS.

August 1843.....	66°
September 1844 ..	64
July 1845	61
June 1846.....	60

COLDEST MONTHS.

February 1843....	37°
December 1844 ..	39
March 1845	38
February 1846....	45

Hottest year ..... 1846.
Coldest year ..... 1845.

52° Average Mean Temperature. May 1843, April and May 1844, and May 1845, represent the Mean Temperature.

TABLE E.

From a series of observations, commenced in 1826 and continued to the present period, it is observed that the most rain falls in November, the least quantity in April. The ratio of the year is as follows:—

November, July, September, October, December, January Rainy months.
August, February, March, June, May, April ..... Dry months.

The observations which complete the record for 1846, have been forwarded by the Author since the Meeting.

Notices of a Halo, Paraselene and Auroræ Boreales. By the Rev. T. RANKIN.

The halo occurred on Sunday, October 12, 1845, at 5 P.M., at Huggate in Yorkshire; it formed a portion of an ellipse above the sun, which was in a focus of the conjugate diameter of the ellipse. The inner part of the arc was most luminous.

In the evening of the same day occurred a paraselene, from 7 to 10 P.M.; its diameter was about 20°, and the inner part of the arc was most luminous.

On the evening of October 6, 1837, January 3, 1840, and August 29, 1845, auroræ were noticed at Huggate.

Method of Measuring the Height of Clouds.
By the Rev. W. WHEWELL, *D.D., F.R.S.*

I do not know whether it has been observed how easily the height of clouds may be measured when the reflexion of them can be seen in a lake from a station above it. In that case the angle of elevation above the horizontal plane for any selected point of a cloud is not equal to the angle of depression of the image; for the latter angle is the angle of elevation of the cloud *at the point of the lake* where reflexion takes place, and is therefore greater than the former. The difference of these two angles gives us the means of finding the height of the cloud. If α be the angle of depression of the image of the cloud-point, β the angle of elevation, and h the vertical height of the station of observation above the level of the lake, it is easily shown by trigonometry that the height of the cloud above the level of the lake is

$$h\frac{\sin(\alpha+\beta)}{\sin(\alpha-\beta)}.$$

The angles α and β may be measured by any contrivance for measuring elevations and depressions; for instance, a graduated quadrant with a plumb-line, or hanging *alidade*, and plain sights. No great accuracy is attainable or is needed in this inquiry. Hence a table of double entry (there being two elements, α and β) would be a cor

nient mode of determining the multiplier of h. But the multiplier varies rapidly with variations of $\alpha - \beta$; more slowly with variations of $\alpha + \beta$. Hence it would be convenient that a table should be arranged for small intervals of $\alpha - \beta$ (say 1°, or below 1° to 15′), while larger intervals for α might suffice, as 5°. Hence this might be the form of the Table (or rather these the numbers to be calculated:—

$\alpha-\beta=$	0°	1°	2°	3°
$\alpha=1°$	∞	1		
$\alpha=5°$	∞	$\frac{\sin 9°}{\sin 1°}$	$\frac{\sin 8°}{\sin 2°}$	$\frac{\sin 7°}{\sin 3°}$
$\alpha=10°$	∞	$\frac{\sin 19°}{\sin 1°}$	$\frac{\sin 18°}{\sin 2°}$	$\frac{\sin 17°}{\sin 3°}$
$\alpha=15°$	∞	$\frac{\sin 29°}{\sin 1°}$	$\frac{\sin 28°}{\sin 2°}$	$\frac{\sin 2\,7}{\sin 3°}$

And for intermediate values, the multipliers would be given by interpolation. But since the result depends so much upon the value of $\alpha - \beta$, it would be desirable to observe $\alpha - \beta$ directly, rather than by taking the difference of two observations. This may be done thus: take a dark cup full of water, and place it so that the surface of the water in it is seen at the cloud-point reflected in the lake. Also place it so that the boundary of the water in the cup when it falls upon the cloud-speck is in the vertical plane passing through the speck. Then the horizontal edge of the cloud-speck, seen in the lake and in the water-cup, will be *dislocated*, and the amount of dislocation subtends the angle $\alpha - \beta$ at the eye. Hence $\alpha - \beta$ may be measured directly on the limb of the quadrant; or a micrometer affixed to the *alidade* of the quadrant for the purpose of measuring $\alpha - \beta$ may easily be devised. The same formula and process may obviously be applied to measure the height of a *mountain* when h is known. If the height of the mountain be known, h may be deduced by the same formula. Without knowing h, the formula will serve for *comparing* the height of a cloud with that of a mountain, when both can be seen in the lake. The arc $\alpha - \beta$ will usually be very small, and will vary as its sine; and in this case $\alpha + \beta$ will be 2α nearly. Hence, in comparing clouds and mountains, their height will be as $\frac{\sin 2\alpha}{\alpha - \beta}$. Hence the heights of a mountain and of a cloud *seen* very near the mountain top are inversely as the dislocations in reflexion. If the mountain image be dislocated three times as much as the cloud-image, the cloud is three times as high as the mountain. If the altitude be different—for example, if the mountain be 15° and the cloud 45° elevated, and the dislocation still as 3 and 1, the height of the cloud is six times the height of the mountain (for, $\sin 2\times 15° = \frac{1}{2}$, $\sin 2\times 45° = 1$). The same is the case of different *strata of clouds*. When seen in the same quarter, their heights are inversely as the dislocation of their images.—N.B. Perhaps a piece of glass ruled with parallel equidistant lines held at a given distance from the eye would be a good way of comparing dislocations of images.

On the Force of Vapour. *By* Captain SHORTREDE.

The author adopts the experiments of the French Academy at high temperatures, and those of Magnus at low temperatures, as being the most carefully performed and the most extensive of all yet available. In the Academy's experiments, the indications of the smaller thermometer in the steam are preferred to those of the larger thermometer in the water; because the temperature of the water increases with its depth, and always exceeds that of steam formed at its surface, besides the heat which may be necessary to overcome the cohesion of water in passing into vapour.

It is probable, also, that the temperature of the steam in the manometer was, from exposure to the air, less than that of the steam in the boiler, so that the small thermometer may be expected to give the temperature too high rather than too low.

An Account of an Atmospheric Recorder. *By* G. Dollond, *F.R.S.*

It having appeared to be desirable at the last meeting of the British Association that a correct self-registering apparatus should be constructed, by which the various changes of the atmosphere should be recorded upon paper, in such manner that they might be referred to at a future period, I have the pleasure to describe an apparatus which records the indications of the following eight instruments, viz. the barometer, the thermometer, the hygrometer, the electrometer, the pluviometer, the evaporator, the force-board, and the anemometer, in relation to time. I have found it answer the purpose for which it was intended, in every way satisfactorily. 1st. The barometer registers the change which takes place in the weight of the atmosphere at every half-hour, and the line may be traced from one point to the next without any difficulty. 2nd. The thermometer registers the various changes from cold in the night or morning, to the greatest heat in the afternoon, continuously. 3rd. The hygrometer is adjusted to show the changes from dryness to extreme saturation of moisture to every hundredth of the scale, and is extremely steady in action. 4th. The electrometer is acted upon by a conductor, and registers each flash of lightning which comes within the range of the conductor. 5th. The pluviometer registers the drops of rain which fall upon the surface of the receiver, and shows the continuation of the falling quantity until an inch is received; this is then discharged and the process recommences for another inch, and so on continually. 6th. The evaporator is so constructed as to retain a quantity of water with the surface exposed, and so guarded that rain cannot enter into the vessel. The surface gradually evaporates, as shown by a diagonal line upon the paper until an inch is evaporated, when a discharge takes place and another line commences. 7th. The force or power of the wind acts upon a board one foot square, whose movement is registered in pounds and ounces avoirdupois, from one ounce to thirty pounds. 8th. The direction of the wind is shown in circles, which immediately upon inspection show the direction of the course or change which has taken place, for instance, if it has passed through the south or the north, from east to west, and the point from which it started and that to which it returned. All these eight varieties have their scales about half an inch from the marking-points, and can be very easily read or referred to. There are markers on each edge of the paper for time, the paper being carried forward by a clock.

Mr. Dollond gave an account of the storm, as shown by this instrument, at Camberwell on the 1st day of August 1846, during his absence:—

The barometer changed from..... 30·03 inches to 29·82 inches.
The thermometer from..... 69° to 98°

during the day, or twenty-four hours.

The hygrometer ranged from 39° to 80° of moisture.

At two o'clock the electrometer was affected by the lightning, and registered fifteen discharges or flashes in one hour.

At $3^h\ 23'$ the rain commenced falling, and in two minutes the pluviometer discharged an inch, which had previously stood at 11·90 for several days. At $4^h\ 3'$ another inch was registered, and at $5^h\ 25'$ a third inch was marked upon the registering paper; and so tremendous was the fall of rain and hail, that at $5^h\ 35'$ a fourth inch was marked upon the paper, making on the whole 3·12 inches in $2^h\ 17'$.

The force of the wind was equal to one pound four ounces, and the direction changed from east to west, through the south at $3^h\ 20'$.

On the Construction of a Self-registering Barometer, Thermometer, and Psychrometer. *By* C. Brooke, *M.B.*

Mr. Brooke remarked that he had been induced by the want of efficient means of automatic registration of the variation of meteorological instruments, and especially of magnetometers, which was so generally expressed at the last meeting of the British

Association at Cambridge, to bestow some attention to the subject, and was enabled to report to the meeting that he had succeeded in devising a method of continuous registration with as much accuracy as the purposes of science require.

Various mechanical means have been proposed for the registration of all meteorological instruments except the magnetometers; but the amount of magnetic force is so small, that the variations of its intensity and direction are incapable of actuating any mechanism, and therefore can only be expected to be recorded by the aid of photography; and by these means the proposed object had been accomplished: as however a detailed description of the apparatus by which magnetic variations have been registered is already in the hands of the Royal Society, Mr. Brooke did not consider himself authorized to enter into a description of it, further than is necessary to explain those modifications of the apparatus which formed the subject of the present communication. A piece of prepared photographic paper is placed between two concentric cylindrical glass surfaces, which are carried round their common axis, placed horizontally, by the hour-hand of a time-piece movement. The paper consequently passes vertically behind a horizontal slit in a case of suitable form in which the cylinders are enclosed to protect the prepared paper from the influence of diffused light. A cylindrical refractor, the axes of whose surfaces are parallel to the slit, is placed in front of the slit, and at such a distance from it that the rays of light falling on it may be refracted to a focus on the paper. In the case of the magnet, a spherical concave reflector is attached to a stem by which the magnet is suspended, and a camphine lamp having a vertical narrow slit in the chimney is placed at such a distance from it that an image of the slit may be formed at the distance of the paper; a portion of the image is condensed vertically by the cylindrical refractor, and impresses the photographic paper. Some registers obtained by this apparatus were exhibited to the Section, from which the position of the declination magnet might be determined by a scale with a probable error not exceeding $10''$, and in some, not exceeding $5''$.

In obtaining the register of the barometer, a lamp is placed in front of the apparatus, and a screen with a narrow vertical slit attached to the end of the long vertical arm of a lever is interposed between the refractor and the horizontal slit before described. This lever is balanced, and a short horizontal arm rests on a float supported by the mercury in the shorter tube of a siphon barometer; the lengths of the arms of the lever having been taken as 10 to 1, the variation of the height of the column will be magnified 5 times, and the light passing through the point at which the two slits cross, will trace out a line sufficiently distinct to indicate the height of the barometer at any period to the $\frac{1}{100}$th of an inch.

The registration of the thermometer and psychrometer was obtained by interposing the stem of these instruments with a flat bore, wide enough to exclude the light, between the slit and the refractor; as however this expedient is not new, it need not be more particularly described; the only novelty in Mr. Brooke's apparatus was in placing the stems of the two instruments on opposite sides of the cylinder, so as to obtain a register of both on the same paper, and in making the bulbs long narrow cylinders instead of spheres, in order to increase the surface and consequently the susceptibility of changes of temperature. By having each degree about $\frac{1}{3}$th of an inch long, the temperatures may be obtained at any time to $\frac{1}{10}$th or $\frac{1}{30}$th of a degree.

Table of the Fall of Rain in the Lake Districts of Cumberland and Westmoreland, &c. in the Year 1845. *By* J. F. Miller.

The writer exhibited a series of registers in a tabular form, from which it resulted that at Seathwaite there have been 31 days in which the fall was between 1 and 2 inches, five days between 3 and 4 inches, one day between 4 and 5 inches, and one day between 6 and 7 inches.

On the 27th of November, 1845, there was measured at Seathwaite 6·62 inches, and on the 26th and 27th nearly 10 inches, being the greatest quantity of rain which has ever been measured in the same period in Great Britain. At Langdale Head in Westmoreland, the fall on the 27th was 6·28 inches, and on the 26th and 27th nearly 9 inches.

The consequence was the heaviest flood which had occurred at these places for at least sixty years past.

Windermere Lake had not been so high for the last fifteen years; on the night between the 26th and 27th it rose 2 feet in perpendicular height; the quays along the banks of the lake were immersed in water, and much wood was carried away by the current and lost. Keswick Lake had not been so high since November 30th, 1838.

Of the total quantity of rain, measured in the vale of Borrowdale in 1845, 106·58 inches fell in the months of January, March, August, October, November and December; and nearly 46 inches in the two latter months.

Such was the violence of the storm on the night of the 28th of December in the lake districts, that a number of fish were found next day on the margin of Bassenthwaite Lake, which had been thrown up by the waves in the course of the night by the force of the wind,—a circumstance wholly without a parallel, except on the night of the memorable 6th of January, 1839. The rain which fell in the preceding twenty-four hours amounted to 4·22 inches; at Whitehaven the quantity was ·323, or nearly one-third of an inch.

Through the kindness of various gentlemen I am enabled to add returns of the rain in 1845, from several places throughout Great Britain, by way of comparison with the quantities measured in the lake districts.

	inches.
Allenheads, Northumberland	56·411
Kendal, Westmoreland	53·946
Cartmel, ditto	53·665
Rampside, ditto	40·289
Tivil, ditto	40·000
Bolton-le-Moors	48·110
Carlisle, Cumberland	31·280
Brougham Hall, ditto	35·000
Manchester	41·415
Doncaster	29·198
Highfield House, Nottinghamshire	29·595
Cirencester	28·970
Leeds	25·586
North Shields	26·200
Culloden, Inverness, N.B.	27·632
Applegarth Manse near Lockerby, N.B.	30·32
Arbroath, Co. Angus, N.B.	28·211
Liverpool	34·06
Stratton, Cornwall	40·89
Uckfield, Sussex	25·03
Empingham, Rutlandshire	24·61
Helston, Cornwall	37·80
Kelso, Roxburghshire, N.B.	24·42
Makerstoun, near Kelso	21·27

The fall at Seathwaite is more than 3 times the quantity measured at Whitehaven, one of the wettest *towns* in the kingdom. It exceeds the fall at Leeds by 6 times; at Culloden by 5½ times; at Doncaster and Highfield House, Nottinghamshire, by 5 times; at Cirencester and Arbroath by 5¼ times; and at Makerstoun near Kelso, the seat of Sir Thomas Brisbane, Bart., by more than 7 times.

Seathwaite exceeds Doncaster, in January, by 15 times; in November by 21 times; and in December by 9½ times. It exceeds the quantity at York, in January, by 16 inches, or 20 times; in March by 9 times; and in November by 20 times. It exceeded Dublin, in March, by 14 times; in April by 13 times; in October by 5 times; and in November by 7 times.

The quantity measured at Seathwaite and Langdale Head, in the month of December (24·02), is more than falls at some places in Great Britain during a year.

Mr. Miller said, "It is much to be regretted that the meteorology of our lake and mountain districts should have been so long neglected. Prior to the establishment of these gauges, there were none stationed in the lake district of Cumberland, and, so far as I am aware, only two among the lakes of Westmoreland, viz. one at Esthwaite

Lodge, and the other at Grasmere; and the largest quantities measured in any year were 86 inches, and 90 inches respectively. And so startling did these results appear to meteorologists, when first made known, that many were led either to doubt their authenticity, or to suspect the accuracy of the instruments employed.

"But subsequent investigation shows that these values are exhibited in some portions of the lake district of Cumberland only in the very *driest* years. Thus, in the period from July 1844 to June 1845 (which for drought has only found a parallel in the memorable 1826), the fall at Gatesgarth and Wastdale Head amounted to 83·96 and 88·42 respectively, and at Grasmere in Westmoreland to 74 inches nearly. But we suspect that meteorologists will hardly be prepared for the discovery, that we have localities in our own country, which, even in average years, exceed the amount of rain annually deposited in many tropical climates; yet such is the almost incredible fact. At Grenada, lat. 12° 5′, the average fall is 126 inches; at St. Domingo, lat. 18° 20′, it is 120 inches; and at Calcutta, in lat. 22° 35′, it is 81 inches. In the past year the quantity measured in the vale of Borrowdale exceeds the largest of these amounts by 25·87 inches. An inspection of a map of the country in connection with the table will show, that the wettest portions of the lake district are those situated at the head or eastern extremity of those valleys formed by our highest mountain ridges, amongst which are the Great Gabel, Sca Fell, Glaramara, Red Pike and Honister; the first being apparently the grand central point of attraction and condensation for the warm vapour arriving in a south-westerly current across the Atlantic; and it is a remarkable coincidence that nearly all our lakes bear in the direction of Gabel, so that if extended onward in a direct line, they would all converge at the base of this noble mountain.

"Immense as is the deposit of rain at Gatesgarth, Grasmere, Wastdale, and in other portions of the lake district, even these enormous quantities sink into comparative insignificance when compared with the fall at Seathwaite, a small hamlet at the head of the vale of Borrowdale, which exceeds the wettest of the other localities by 27·74 inches, or by one-fourth nearly. Now it is chiefly the deposit in the vale of Borrowdale which supplies the majestic river Derwent and the extensive and picturesque lakes of Derwent and Bassenthwaite, so that we might *à priori* have expected to find the greatest amount of rain in this section of the district.

"The great difference in the fall between places closely contiguous to each other is very remarkable: the proportion which obtains between Ennerdale lake, and a farm-house about 1¼ mile distant, is as 2 to 1 nearly.

"Loweswater, Buttermere and Gatesgarth are all in the same line of valley, surrounded by the same ridges of mountains, and are each distant about 2 miles from the other. Buttermere exceeds Loweswater by 18 inches or one-fourth; but Gatesgarth, at the head of the valley, exceeds Buttermere by 36·65 inches, or nearly one-half. Here the difference between the head and foot of the valley, in a distance of 4 or 5 miles, is 54·588 inches.

"But the great increase in the fall towards the head of the valleys is appreciable at much more limited distances. At Wastdale Head I have two gauges of precisely the same size and shape, and within a quarter of a mile of each other, yet the difference of the receipts in a single month sometimes amounts to half an inch.

"The annexed statement will show that the excess is always in favour of the higher gauge marked No. 1.

1845.	No. 1.	No. 2.	Diff.
October	12·35	11·89	·46
November ...	12·31	11·90	·41
December ...	16·18	15·78	·40
1846.			
January	12·97	12·47	·50
February ...	6·60	6·58	·02
March	10·35	10·07	·28
April	6·59	6·16	·43
May	3·65	3·44	·21

"The current of vapour is apparently only partially decomposed in passing over a flat or even an undulating country; it aims at once for the loftiest heights, passing over the less hilly districts with little diminution of its original weight or volume. But on reaching the mountain peaks, the sudden change of temperature causes a rapid and continuous condensation in the form of vast torrents of rain, whilst comparatively little descends on the adjacent plains.

"As an instance of the low temperature on our mountain tops, I may mention that on making the ascent of Skiddaw, on the 5th of September last year, the thermometer on the summit, at noon, stood at 41°; sky overcast, the sun gleaming out at intervals. The temperature of a strong spring, about 2 miles from the summit, was also 41°. The temperature of the air at the foot of the mountain, at $3^h\ 30^m$ p.m., was 58°.

"Snow not unfrequently continues on Sca Fell till the middle or end of June; we remember seeing a patch on the 15th of June, 1843; and on the neighbouring mountains the air was so intensely cold that we think it could not be more than 2° or 3° above the point of congelation. That the rapid increment in the fall of rain in approaching mountainous districts is owing to the causes above alluded to, and not to the greater number of wet days, is evident on an inspection of the table, where it will be found that we have as many wet days at Whitehaven near the level of the sea; indeed it rarely rains in the lake districts, that the day is not also wet, more or less, at the coast.

"And in comparing the number of wet days at various places, we not unfrequently find them to obtain in the *inverse* ratio to the fall of rain; thus, in 1845, they range from 195 to 211 in the lake district; but at Manchester, with a fall of 41 inches, they mount to 235; at Culloden, with a fall of 27 inches, to 237; but at Kendal, where the quantity of rain is 53 inches, the wet days are only 178.

"At Carlisle the wet days are the same as in the lake district, where the fall is four times as much.

"We are informed by a gentleman recently returned from India, who was many years medical attendant to the Rajah of Sattarah, that he seldom measured more than 40 inches of rain in the plain, but among the hills 30 miles distant, the annual quantity reached 350 inches; and as much as 9 inches has been known to fall in 24 hours.

"The utility and beauty of this arrangement is obvious, since the mountain torrents afford a continuous supply of water to the lakes and rivers, which otherwise could scarcely have an existence. The rivers thus called into being aid the efforts of the husbandman by carrying off the superfluous moisture from the plains, which, without such a provision, would be in danger of stagnating into pestilence."

Readings of Mountain Gauges, June, July and August 1846.

By J. F. MILLER.

	Feet above Sea.	June.	July.	August.
		inches.	inches.	inches.
Whitehaven *	100	2·311	9·061	4·066
Scilly Banks, near ditto..	500	2·103	8·626	3·465
Sca Fell Pike.....	3166	5·000	14·380	7·050
Great Gable	2925	7·60	16·870	8·650
Sparkling Tarn.....	1900	6·55	22·730	12·030
Stye Head Pass	1250	6·26	17·760	11·030
Valley (Wastdale)...	160	5·33	16·820	8·960
Seatollar (Borrowdale)...	1850	5·79	18·350	8·150
Valley (Seathwaite)	300	6·29	22·125	10·480

In March, April and May, the higher gauges received less rain than the lower; in June the reverse of this is the case, owing doubtless to the greater elevation of the nimbi or rain-clouds in the warmer months, and especially when the air is highly charged with electricity, as was the case last month.

* On the spire of St. James's Church, eighty feet above the street, 1·680.

The number of gauges in the lake districts, in addition to the above, is twelve, most of which are read off daily.

It would appear from the average results since April last, that the amount of rain increases from the valley upwards, to an altitude of about 2000 feet, and gradually decreases above that elevation; thus the gauge at Sparkling Tarn (1900 feet) almost invariably receives *more* than any other of the gauges; much however depends upon the position of the mountain with respect to the prevailing wind; thus the gauge on Seatollar (nearly the same elevation as Sparkling, but bearing nearly due north) invariably receives *less* rain than the valley *at the end of a month*; nevertheless, measurements made at short intervals, when a north or north-west wind had prevailed, show that it sometimes receives considerably *more*.

Fall of Rain on the Coast of Travancore and Table Land of Uttree, from Observations of M. General Cullen, *Resident in Travancore. By* Lt.-Colonel Sykes, *F.R.S.*

At former meetings of the British Association I have had the means of submitting to the Physical Section facts illustrative of the meteorology of portions of Western India, particularly at great elevations, such as at Mahabuleshwur, near Sattarah, at the height of 4500 feet above the sea, and at a distance of about 30 or 40 miles inland. It was shown that the fall of rain in one monsoon was of the prodigious amount of 302·21 inches, or more than 25 feet depth of water. At a similar height at Merkara in Coorg, about 5° of latitude S. of Mahabuleshwur, and in about the same longitude, and at 65 miles from Cananore on the coast, the mean fall of rain for the years 1838, 1839 and 1840, was 143·35 inches. Communications from my friend General Cullen, the British minister at the Travancore court, enable me to extend the meteorological observations, at least as far as relates to temperature and the fall of rain, to Cape Comorin, supplying also data for a comparison of the fall of rain on the coast and at short distances inland, at a considerable elevation. I may state that we are indebted for the present communication from India to the stimulus occasioned by the publication of the Mahabuleshwur and Merkara observations in the volumes of the Association. General Cullen's letter to me is dated Cochin, the 27th of July 1845, and he states that he had been in the habit for many years past of observing the meteorology of his location, wherever that might be, but that the pressure of his public duties had disabled him from reducing and arranging the observations, particularly the barometrical. He had, however, been enabled to transmit to the government of Madras, statements of the fall of rain along the western or Malabar coast of Hindoostan, from Cape Comorin in Travancore, lat. 8° 4′, to the town of Cochin and to Panlghatcherry, in lat. 10° 45′, as well as at several inland stations in the provinces of Cochin and Travancore; and in the Company's district of Tinnevelly, on the east side of the Ghâts, for the years 1841, 1842 and 1843. These statements were accompanied with explanations which I shall shortly notice. In the year 1841 the stations selected in Travancore were 5; but the observations did not commence at Nagercoil, Trevandrum and Quilon, before the month of May; and at Allepy and Cochin in the month of June. The stations on the east side of the Ghâts were 3; at Vaurioor the observations commenced in June, at Shenkotah in July, and at Palamcottah not before October. As the observations are not for equal periods, I shall confine myself to observing that both the Malabar and Coromandel coasts appear to have been subjected to both monsoons, the S.W. and N.E. rain having fallen at all the stations in the months of October, November and December, as well as in the usual S.W. monsoon months of June to September inclusive. In the year 1842 the stations in Travancore and Cochin were extended to 8, and the observations were for the whole year, with the exception of Tritchoor and Chittoor, where they did not commence until May, and at Koravantavalum, where they did not commence until August. At the three former stations in Tinnevelly the observations were for the whole year. In this year, although both monsoons appear to have operated upon both coasts in the months of August, September, October and November, yet in the month of December rain only fell on two days on the Travancore coast, and only five times at Palamcottah on the opposite coast. The same discrepancies exist with respect to the months of January, February and March, rain having only fallen on thirty-eight days at all the eleven stations together, on both coasts,

during those three months. In the year 1843 Cape Comorin is added to the eight stations in Travancore, and the observations at all the stations are for the whole year. At Cape Comorin, at an elevation of fifty feet above the sea, we have the singular fact of not a single shower having fallen in the months of February, March, April, August and November, months belonging to both monsoons; and the fall for the whole year at Cape Comorin was only 19·2 inches. At Palamcottah, on the Coromandel side, there was not a single fall of rain in the months of June, July, August and September, and only 1 and 3 and 1 and 4 falls respectively in the months of February and March, at all the stations in Tinnevelly. The total fall at each station exhibits a rapid increase in quantity, in increasing the latitude, as is shown by the annexed tabular statement.

	Travancore.											
	Cape Comorin, 50 feet above sea.		Nagercoil, 150 feet above sea.		Trevandrum, 130 feet above sea.		Quilon, 30 feet above sea.		Koravantavalum, 300 feet above sea.		Allepy, 30 feet above sea.	
	No. of days.	Rain. Inches.	No. of days.	Rain. Inches.	No. of days.	Rain. Inches.	No. of days.	Rain. Inches.	No. of days.	Rain. Inches.	No. of days.	Rain. Inches.
From May only, 1841	...	...	73	46·8	103	86·07	124	94·76	...	...	140	96·8
1842	...	...	63	35·7	97	57·7	131	81·06	Incomplete		168	104·5
1843	32	19·2	71	42·6	124	85·45	121	105·7	152	129·0	184	131·85

	Cochin.						Tinnevelly.					
	Cochin, 20 feet above sea.		Tritchoor, 60 feet above sea.		Chittoor, 400 feet above sea.		Shenkotah, 600 or 700 feet above sea.		Palamcottah, 200 feet above sea.		Vaurioor, 60 feet above sea.	
From May only, 1841	124	77·3	...	...	...	...	28	3 ·48	From Oct. 20	14·57	29	18·05
1842	119	105·27	Incomplete. 129	104·4	Incomplete. 82	52·3	51	39·45	71	23·1	60	20·27
1843	138	124·49	115	80·15	108	68·6	68	48·1	58	26·9	66	25·75

It exhibits also the fact of the total fall on the Coromandel side bearing no comparison to that on the Travancore side. For instance, at Shenkotah, at the east base of the Ghâts, sixty miles from the sea coast of Travancore, and about eighteen miles due east of Koravantavalum on the west side of the Ghâts, and forty miles from Quilon, the fall of rain at Shenkotah was 48·1 in. in 1843, and at Koravantavalum 129 inches, both places being at a considerable elevation. Palamcottah again is in the latitude of Quilon, is sixty miles from the western coast, and thirty miles east of the chain of Ghâts. Here the fall of rain was 26·9 inches in 1843, while at Quilon, on the western coast, the fall was 105·7 inches. Cape Comorin and Vaurioor are placed in the same category, but the former is in Travancore and the latter in Tinnevelly, the latter being only *three* miles N. and a little E. from the former; but the difference is 6½ inches of rain in favour of Vaurioor. The next feature is the singularly limited fall of rain at Cape Comorin and Vaurioor, both of them situated at the extremity of the peninsula of India, and both freely exposed to the first action of both monsoons, N.W. and S.E., and yet the amount of rain is not one-fifth the amount of that which falls at places on the Travancore coast, a few miles N.W. Nagercoil is the next station to Cape Comorin and comes into the same category, but it is nine miles inland, and though so near to Cape Comorin, has a fall of rain more than double that of the Cape. The next feature is the great and *progressive* increase in the fall of rain which takes place at the respective stations as they lie north-westward from Cape Comorin, along the western coast. Trevandrum, Quilon and Allepy, are apparently under nearly similar physical circumstances on the coast, yet the first in 1843 had only 85 inches, the second 105, and the last 131 inches of rain. Chittoor, which is fifty-five miles in-

land E. from Quilon, and in the gorge of the great gap in the Ghâts at Palghat, which opens to the Coromandel coast of Tinnevelly, and on the high road it might be said of the aqueous vapour of both monsoons, had only 68 inches, while Allepy, on the open coast, had 131 inches, and Cochin 124 inches. The fall is greatest on the sea coast, diminishes at stations inland to the foot of the Ghâts, but, as I shall have occasion to show, increases enormously on ascending the Ghâts to their plateaus or table-lands.

General Cullen says it is difficult to attempt explanation of the differences in the amount of rain exhibited in his tables; but he offers some remarks on the winds and physical structure of the country as necessarily influencing the distribution of rain. The peninsula of India, as is known, is in a triangular form, the apex of which is Cape Comorin. The western Ghâts in maps appear to run continuously without break from Cape Comorin to the 24 or 25° of latitude N.; but such is not the case. The land within the apex of the triangle to Palghat, a distance of 150 miles, rises precipitously into a table land 2000 or 3000 feet high, with peaks and masses attaining an elevation of 5000 or 6000 feet. It has at its sides a narrow low tract of land on both coasts. In the latitude of Palghat, this table land suddenly terminates in a chasm or gap forty miles long by thirty miles broad, without a single hill or ridge. There are other gaps, but of less marked character; in one of these stands Shenkotah. It might be supposed the continual passage of aqueous vapour through these gaps would continually drench them; but such is not the case, as the vapour passes through only partially condensed; for Chittoor, which is at the western gorge of the Palghat gap, has only 68 inches of rain and Shenkotah only 48 inches; both however have rain in every month of the year, excepting February at Chittoor, and in the month of November, at both places, there was only one fall of rain. The paucity of rain at Palamcottah, General Cullen attributes to the intercepting of the vapour of the western monsoon by the table lands of Travancore. But this does not explain the paucity of rain at Cape Comorin and Vaurioor, which are open to both monsoons; and why should they not be deluged at least by the S.W. monsoon as well as Allepy or Cochin?

General Cullen made the observations which I have adverted to without a view to the illustration of any particular meteorological phases or phænomena; but observing the publication in the annual volume of the Association of the extraordinary fall of rain at high elevations, as at Mahabuleshwur and Merkara, he was induced to ascertain whether a similar fact obtained on the high lands of Travancore. He therefore, on the 23rd of June 1844, established a pluviometer at a spot called Uttree Mullay, thirty miles E.N.E. of Trevandrum, at an elevation of 4600 feet above the sea (about that of Mahabuleshwur), and continued his observations simultaneously with others at Trevandrum and Quilon on the coast until the end of December. The fall of rain on the table land was 164 inches, while the fall at Trevandrum and Quilon respectively was only 36 and 36¼ inches. The variation of the monthly mean temperature at Uttree Mullay was only from 64° to 67° Fahr., and at Trevandrum from 77½° to 78½° Fahr.

	Temperature.		Rain.		
1844.	Uttree Mullay, 4600 feet.	Trevandrum, 130 feet.	Uttree Mullay, 4600 feet.	Trevandrum, 130 feet.	Quilon, 30 feet.
June 23 to 30	66°	78½	7½	0½	0½
July.....	67	78	26¼	3½	5½
August.....	64	78¼	23	5½	6½
September ...	66	78½	6	3¼	2½
October	66	78½	41½	15½	14
November ...	65	77½	36¼	4½	3½
December ...	64	78	23	2¼	3½
Total.....	65½	78½	164	36	36

Had the observations extended through the whole year, no doubt the contrast would

have been much greater; but as it is, it is sufficiently remarkable*. Above 100 inches of the rain which fell at Uttree Mullay occurred in the months when the S.W. monsoon is considered to have ceased on the western or Malabar coast, and may therefore be said to belong to the N.E. monsoon of the Coromandel coast. There appear to have been two occasions when the fall of rain was remarkable in twenty-four hours. On the 10th of October there fell 9 inches, and on the 26th of November there fell 7·35 inches; but there also fell from the 6th to the 10th of October inclusive, 29·4 inches, averaging nearly 6 inches daily, or more than falls in most of the counties in England in a twelvemonth. I am glad to communicate the assurance of General Cullen, that not only will he continue these interesting observations throughout the year, but that he has also established two pluviometers in the central table land of Travancore, which is about thirty miles across to the Coromandel side; one at Perregaar at 2300 feet, and another on the eastern or Coromandel edge at an elevation of 3600 feet. General Cullen considers the area of this table land to be about 2000 square miles, much of it at an elevation of 4000 feet. He states that it is lost to civilization, from the Travancore government drawing only cardamoms from it, and rigorously prohibiting culture to protect their cardamom monopoly. The main features of these observations correspond with those of Mahabuleshwur and Merkara, and testify to one of those benevolent provisions of nature which the inquirer always meets with, of the continuous impingement of aqueous vapour upon mountain masses, occasioning very great condensation, and furnishing the perennial sources of springs and rivers. The apparent discrepancy of the comparatively small fall of rain at Chittoor, situated in the midst of the great gap of Palghat, confirms this view; for though the vapour is constantly driving through the gap, it does not meet with any impediment to force it up into a much lower temperature than its own, and it is therefore only partially condensed. The paucity of rain however at Cape Comorin and Vaurloor, both open more or less to both monsoons, does not admit of a ready solution. If, as General Cullen asserts, the S.W. moonsoon beats rather from the N.W. and westerly points than from the S.W., it cannot be said that Ceylon intercepts the vapour from Cape Comorin; and then, why is there a fall of 131 inches and 124 inches respectively at Allepy and Cochin on the open coast, and only 19 inches at Cape Comorin? With respect to the N.E. monsoon, some of its vapour may be cut off from Cape Comorin by shoulders or peaks from the table land of Travancore, and yet the whole mass of the table land does not prevent Trevandrum and Quilon from receiving a portion of the N.E. monsoon, as is shown in the preceding table. A closer attention to local physical circumstances is evidently necessary before a rational account can be given of these discrepancies; but General Cullen is too zealous an observer not to work out the question; and I look to being enabled, at a future meeting of the Association, of laying before this Section a continuation of General Cullen's observations and a satisfactory solution of the existing difficulties.

On a New Portable Azimuth Compass. *By* E. J. Dent, *F.R.A.S.*

Mr. Dent exhibited this instrument. The magnetic needle was suspended in an inner case, and that again fitted in an outer case in such a manner as to admit of having either its ends reversed so as to eliminate errors of centring; or its faces reversed so as to eliminate the error of collimation.

On the Relations of the Semi-Diurnal Movements of the Barometer to Land and Sea-Breezes. *By* Thomas Hopkins.

Mr. Hopkins exhibited diagrams, drawn up from Col. Sabine's paper 'On the Meteorology of Bombay,' of the diurnal temperature curve, total pressure curve, and gaseous pressure curve; with a diagram representing the swelling and sinking of the land and sea-breezes; and endeavoured to show that these were inconsistent with the explanation given by Col. Sabine, but harmonized with alternations of pressure caused by the alternate extrication of heat and absorption of it during the alternate evaporations and depositions of water, in the state of clouds and dew.

* Since this paper was read it has been ascertained that the fall of rain for the whole year was 290 inches.

Abstracts of Meteorological Observations made at Aden in 1845. *By* WILLIAM MAYES, *Serjeant in 7th Regiment.*

I. Hourly Means, for the Month of February, of the Temperature of a Thermometer observed in the Sun.

Time.	Mean of Therm. Readings.	Max.	Min.
8 A.M.	83·9 —	90·0 —	80·0 —
9	88·5 —	93·2 —	80·0 —
10	91·9 +	97·3 +	82·0 —
11	95·1 +	99·2 +	90·0 +
12	96·9 + + max.	100·2 + + max.	90·0 +
1 P.M.	96·1 +	99·3 +	92·0 + + max.
2	94·4 +	98·2 +	90·0 +
3	91·5 +	94·0 —	86·0 +
4	87·9 —	91·2 —	84·0 —
5	82·5 —	86·0 —	79·0 —
General Mean for the hours observed	90·9	Mean max. 94·8	Mean min. 85·3

The readings above the average are marked + (the maxima being marked + +), and those below the average —.

II. Means of Dry and Wet Bulb Thermometers, in February 1845, at the following Hours.

Hour.	Dry Bulb.	Wet Bulb.	Diff.
2 A.M.	76·9	73·7 — —	3·2
4	76·6	73·9	2·7
6	76·4	73·8	2·6
8	78·4	74·4 +	4·0
9	79·9	74·7 +	5·2
10	80·8	75·3 +	5·5
12	81·9	74·9 +	7·0
2 P.M.	81·5	75·4 +	6·1
4	79·9	74·7 +	5·2
6	78·8	74·3	4·5
8	78·3	74·2	4·1
9	77·8	74·3	3·5
10	77·9	74·8*	3·8
12	77·9	73·9	4·0
General Means as stated by the author	79·0	74·3	
Means deduced from the columns	78·8	74·4 +	4·4 —

III. The barometric curve at Aden on the 24th and 25th of March 1845, corrected for temperature, had two maxima, viz. a principal one at 10 A.M. and a lesser one at 10—11 P.M.: it had two minima, viz. at 2—3—4 P.M. and 4 A.M. The extreme diff. from the lowest min. (2—3 P.M. on the 24th) to the highest max. (10 A.M. on the 25th) is 30·074 — 29·859 = 0·215. The author appends a column of corrections for the moisture of air.

Meteorological Observations taken at Fort George Barracks, Bombay, in July, August, September and October 1845. *By* WILLIAM MAYES, *Serjeant in 7th Regiment.*

The instruments observed are dry bulb thermometer, wet bulb thermometer, and

* In the MS. this is written 74·8, but the correct mean is 74·1.

(for part of the time) rain-gauge. The wind is recorded in direction and estimated in force; and the state of the sky and character of weather are noticed several times daily.

The hours for registration of instruments are sunrise, 9 A.M., 2 P.M., sunset, 9 P.M. The max. min. and range of the daily observations are entered, with the several observations in tables. [After the 7th of October the observations were taken at Calabar Barracks.] We extract the following general results:—

	Mean Temp.	Mean Max. Temp.	Mean Min. Temp.	Extreme Max. Temp.	Extreme Min. Temp.	Mean diff. of Dry and Wet Bulb.	Extreme diff. of Dry and Wet Bulb.
July.....	82·8	85·3	80·3	91·0	78·0	4·9	9·0
August.....	81·3	83·8	78·8	86·5	77·0	4·1	7·5
September..	81·7	84·7	78·8	89·0	76·8	5·0	9·0
October.....	85·0	89·9	80·1	97·2	74·0	7·9	10·6

New Experiments on Electro-Magnetism. *By* Prof. WARTMANN.

Since the discovery made last year, by Dr. Faraday, of the action of magnets upon polarized light passing through different media, it became interesting to ascertain whether this influence is limited to the rotation of the plane of polarization of the ray. Numerous experiments have shown that no change whatever is undergone by the fixed lines of the spectrum, either in position, or in quantity or visibility, when they are produced by rays of natural or artificial light, common or polarized, which have been made to go through different substances, such as air, nitrous acid gas, water, alcohol, oil of turpentine, syrup of sugar, a solution of ferruginous alum, or a long prism of flint glass, put in the sphere of action of powerful electro-magnets. As far as those researches have been brought, they lead to the conclusion, that neither light nor the medium suffers any constitutional derangement which could alter the property of the ray to be partially absorbed when it is refracted through a prism. The view generally entertained by foreign philosophers as to the real action of the magnet being one upon the material substance which gives way to the luminous ray, it became necessary to test whether the new magnetical state of molecular equilibrium would not be concordant with some new properties of chemical affinity. Indeed, it has long ago been asserted by Ritter, Fresnel, Hansteen, Murchmann, Lodeck, Murray and others, and more recently by Mr. Hunt, that the magnets have a decided influence upon chemical phænomena. I have taken advantage of powerful electro-magnets, which are put in action by sixty pairs of Bunsen's battery, to make some fresh trials upon the subject, convinced that such means would afford me an opportunity of witnessing, if any, far more decisive actions than those which have been described. But all my attempts have proved unsuccessful to produce any difference in the electrolysis of acidulated water of ferruginous dissolutions, or in the electro-chemical decomposition of sulphate of copper, or of acetate of lead by soft iron. All the results have been carefully and repeatedly tested by accurate weighings; and in the case of the electrolysis of water, I employed electrodes of soft iron gilt by electrical process, and supported by the very poles of the magnets, with the interposition of a film of mica as thin as possible. The apparatus have been placed in all directions relative to terrestrial magnetism, and the poles of artificial magnets have been made to act both separately or together, without any different result whatever. But in expressing this my opinion, I must add that I mean not to say that magnetism is not able to interfere with molecular disposition, which is quite a different view of the subject, though it has not perhaps been sufficiently distinguished from the former one. Indeed we have ample evidence that this is the case under favourable circumstances. These experimental inquiries have led me to ascertain two facts which it may perhaps not be improper to state here. If a chemical action is produced by the immersion of two pieces of soft iron into a liquid which is able to corrode them, or to be decomposed by the metal, and if the poles of a magnet be applied upon these cores, an el

tro-magnetic rotation takes place all round each, which is in the sense of the hypothetic currents of Ampère. Prof. Grove has just pointed out to me that such an action had been stated by Dr. Christie, though, as far as I know, it had been referred to by no treatise on electro-magnetism, and that he himself had witnessed the phænomenon many times. The other fact seems to be of a higher interest, since it declares, as it were, to the eye, what may be called the lines of chemical affinities. I shall now content myself by merely describing what I have been able to witness and to show to many scientific men, reserving for a future occasion to complete this communication and to dwell upon the theoretical part of the subject. Common sulphate of copper is to be dissolved in water, and a cylinder of soft iron dipped into it; as soon as the first deposit of copper has taken place, it is easy to perceive all round the cylinder light films of a blue matter which are extending themselves as diverging rays from the very centre of the cylinder which may be thought to represent the centre of the chemical action. I suppose this substance to be a subsulphate of copper, and Prof. H. Rose is of the same opinion; but from want of time and scarcity of matter, I have not yet been able to submit it to analysis. During the progress of its manifestation, the nature of the liquid is always varying, sulphate of iron taking the place of a corresponding quantity of sulphate of copper. When this change has reached a certain extent, the phænomenon ceases to spread. It is then like to a large passion-flower, with slender stamina terminated by a continuous circular and opake ridge of thick antheræ. Its figure, which is altogether independent of the nature and the form of the vessel, is very geometrical. After half an hour, more or less, this extraordinary design fades by the deposition of the matter at the bottom of the trough. When two cylinders are used in the same plate, two of the rays meet each other perpendicularly on the line of shortest distance of the centres. Others join in direction more and more oblique, and being totally deprived of the faculty of entering their relative dominions, they incurve themselves in hyperbolic arches. Thus a perfectly straight line is formed which cuts into two halves the line of shortest interval. It is scarcely necessary to add that the rays which are not to meet others, extend as in the first case described. With three centres situated at the summits of an equilateral triangle, the lines of separation intersect each other in a point which is at equal distance from the summits, and thence run perpendicular to the three sides of the triangle. The diverging rays, opposite in two directions, are much inflected. The whole of the figure is perfectly regular. These rays are not affected in their development by the magnetization of the cylinders; at least, if one observation made on this point suffices for deciding the question. If there are but two cylinders, and if they are lifted up in the liquid by means of an appropriate horse-shoe magnet, it is possible to move them very slowly without any disturbance of the figure, and particularly without the least incurvature of the line of separation, which follow the cylinders backwards and forwards, as if firmly tied together. But a shock loosens all those particles geometrically adherent; they fall down, and all the design vanishes.

Summary of Researches in Electro-Physiology. *By* Prof. MATTEUCCI.

In the first place he described the experiments which prove that the development of electricity in living animals is a phænomenon appertaining to all organic tissues, and principally to muscular fibres, and that it is a necessary consequence of the chemical processes of nutrition. He particularly wished to prove that the development of electricity in the muscles can never produce electric currents which circulate either in the muscular *mass* or in the nerves. It is only by a particular arrangement of the experiment that we succeed in obtaining a muscular current.

Further, all experiments contradict the opinion of an electrical current existing in the nerves. M. Matteucci proved that the current said to be proper to the frog is on the contrary a general phænomenon which exists in all the muscles that have tendinous extremities unequally distributed, and that this current, supposed to be peculiar to the frog, is only a particular instance of muscular current. In the second place, the Professor laid before the Section his last researches on electrical fishes. He showed that the laws of the electrical shock of these animals are a necessary consequence of the development of electricity, which is produced in each cell of the electrical organ under the influence of the nervous power. In the third place, he showed the relation which exists between the electrical current and nervous power, and proved that mus-

cular contraction is always produced by a phænomenon analogous to the electrical spark, and that the electrical current does but modify the nervous excitability. On these facts M. Matteucci establishes a simple theory of electro-physiological phænomena. In the last part of his communication he treated of inducted contraction; and after having demonstrated that these phænomena cannot be explained in supposing an electrical discharge of any kind indiscriminately, he concluded that inducted contraction is an elementary phænomenon of the nervous power, which acts in muscular contraction, and is analogous to all the actions of induction of physical forces.

On the Identity of certain Vital and Electro-magnetic Laws.
By Joseph Bullar, *M.D.*

The object of this paper was to show that the direction and formation of blood-vessels and the capillary circulation through them, which is independent of the propulsive power of the heart, are in accordance with laws of the vital force, identical in their direction and relation to each other with those of the electro-magnetic force. In such an investigation the *forms* of bodies were considered of the highest importance. Growth is invisible, but the forms it produces are the evidence of the unseen vital force, and by announcing its direction, determine its law. To seek therefore the primary forms of which others are mere varieties, and to ask, "From what direction of the living force does such a form derive its shape?" is a legitimate step towards the discovery of the cause of that form, the "formal cause" of Bacon, or the law in modern language. The formation of blood and blood-vessels in the germinal membrane which grows round the embryo during the incubation of a hen's egg, was taken as a simple type of this process. The small whitish disc on the yolk-bag (the cicatricula), is the spot where the vital changes begin. The embryo occupies the centre of this spot, and becomes the centre of the vital force excited by the mother's warmth. From this centre the force is communicated to the yolk-bag. The disc enlarges, still keeping its circular form, and marked by concentric circles more or less perfect. The disc is produced by the conversion of the yolk into cells, which adhere as a thin circular layer. The circular *form* of this disc and the general concentric arrangement of the cells, were considered to indicate that the lines of vital force which arranged and preserved that form were circular. The next step is the conversion of a portion of these cells which form the disc into blood and blood-vessels. The trunks pass in the direction of radii of the original disc and central germ. The main trunks unite at the central heart, which is at first only a bent portion of the common trunk. The capillaries inosculate at the circumference; thus the vessels form a complete circle. This circular arrangement of the vessels as radii indicates a second circular force at right angles to the plane of the former one. The vessels are formed thus. Those called by Harvey "vasa lutea" are coarse, and the stages in their formation are more easily watched. They are formed in the substance of the disc, and out of the same material,—the cells of the yolk. These cells continuing to accumulate, some are arranged as cylinders, then in succession as half-circles, circles, net-work, and trunks converging to the central embryo. At this stage each vessel is a coarse yellowish cylinder, with a red streak down its axis. Externally it is composed of cells of various sizes, which can easily be brushed off from the semi-transparent tube which they cover, and which is composed of smaller cells, and contains the red blood flowing towards the centre. The inference drawn was, that this tube, formed of cells around the current, is the evidence of a circumferential force around the current, arranging the cells as a tube. It was next shown that such a direction and relation of the vital force in arranging the disc and its vessels were in accordance with the direction and relation of the electro-magnetic force. The law of this double force, which bears on the present inquiry, is, that in order to act both currents must circulate, that is, each must return into itself. That the galvanic force must circulate, is evident from the construction of a galvanic cell. The magnetic force accompanying the galvanic obeys the same law. It also circulates, but in a plane at right angles to the galvanic. Dr. Wollaston called it, in consequence of its circulation, vertiginous magnetism. These two currents are inseparable. They are *directive* forces, or *carrying*, according to the condition of matter on which they act. What is true of the magnetic current circ round a single wire conveying the galvanic current, applies to two or more

put together as a ribbon, or to a slip of metal, the only difference being the increase of force in the latter instances. If the galvanic wire be bent in a circle, or if several wires are arranged so as to form a series of concentric rings, or if, which is the same thing, a spiral coil of wire be made, the magnetic force still retains the same direction as in the straight wire; but as the whole of the wire acts upon the circle of magnetic force, its direction is through the centre of the ring or coil. If such a spiral coil be placed on iron filings, they arrange themselves in lines, passing through the centre parallel to its axis, and then folding up on either side as radii round the edge, where they meet. These experiments were quoted from Dr. Faraday. Such a spiral coil, through which galvanic force circulates, was considered to represent the disc around the embryo; and the iron filings to represent the direction of the capillary vessels, arranged circularly in a plane, at right angles to the disc, by the magnetic force accompanying the galvanic. From comparing the two, the conclusion was drawn, that in both cases the force at work obeys the same laws; that the formation of a circular living disc, by a central force constantly acting, proves the existence of a circular force around that centre, and is analogous to a flat spiral or disc, through which the galvanic force is circulating; and that this vital force in the disc is necessarily attended by a second circulating force in the direction of radii to it, such as is indicated by the vessels. The actual movements of the cells in this living process are invisible, as it is one of growth; but the *forms* produced are explicable on the hypothesis that the living force acts in accordance with the laws of a force the direction and relation of which have been ascertained. This analogy is rendered still more probable by the connexion between heat and galvanism discovered by Seebeck. If a current of heat instead of a current of galvanism be made to circulate through the spiral coil of wire, it will, like galvanism, develope magnetic currents in the direction of radii to the centre. Now as the mother's heat is the source which supplies force to the embryo, in both instances, in the metal coil of wire and in the disc the force is in the form of heat. In both there is a primary concentric arrangement of matter for the transmission of this force; and in both there is the evidence of a second circular force in a plane at right angles to the first.

If, instead of the arrangement of the galvanic wire as a flat spiral coil, the rings are arranged side by side, as a spiral *tube* or *helix*, then the second or magnetic force would be through its axis. It would be a tube, which, if placed in water, would carry one pole of a magnetic needle, floated on cork, through it; and iron filings would arrange themselves in a circular line, going through the helix, round on the outside, returning into itself (Faraday). The spiral galvanic force here is attended by the current through the tube. The converse would be the case. The steps in the formation of vessels are, that blood is first formed, and when it circulates a tube is formed around it. The current of blood indicates a force through the axis of the tube; the tube itself indicates a circumferential force around the current to arrange its materials as a tube. The tubes are arranged circularly, meeting at the heart in the centre, and at the capillaries in the circumference. The living tube, if it followed electro-magnetic laws, would have (like the helix of wire through which the galvanic force was circulating) a circular force through its axis; and conversely, this current would tend to form a tube around itself—supposing always appropriate materials. The vital force has evidently appropriate materials in the form of cells. Those cells, which exposed to oxygen become converted into red globules, are moved in a current; thus showing that they are fit matter for the influence of vital force in one direction, and that such a force is moving them; whereas the smaller cells are arranged round the current as a tube; thus showing a second force at work around the first. There is a current in one direction, and a tube around it; neither tube nor current can be explained without the assumption of a moving power: both are readily explained by two circular forces having the same relation to each other as the electro-magnetic.

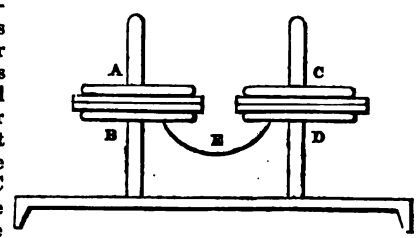
The cells out of which the disc and vessels are built have been regarded so far as under the influence of a force external to them. But each cell has a vital force of its own, similar in kind to the central force, but less in degree. The central force subordinates all lesser forces and makes the disc *one*. Embryologists have shown that the earliest appearance of organization in the ovules of plants and ova of animals is a cell, and that such cell has a nucleus, and each nucleus a nucleolus, or central spot, which is the essential part of each cell, and which has the power of forming cells and of arranging them round it. Dr. Barry has shown that each secondary cell becomes

in its turn the centre of a similar action, smaller ones being generated and arranged round the larger ones. Prof. Goodsir finds that the inner membrane of the tubes of glands is formed of cells, and that nucleated cells are found among them, which he calls centres of nutrition, as if these nucleated cells were the parents of successive broods of young cells passing off from them, and arranged round them as centres. These centres of nutrition are here called centres of force; and according to the law of this force, there would be a common centre, bringing all these isolated and secondary centres into one comprehensive whole. The blood corpuscles are also nucleated cells, each having its own central living force, and thus their relation to the vital force whilst circulating is analogous to that which a magnet holds to the electro-magnetic force moving it. Both are bodies containing within themselves these forces.

The vascular disc of the yolk-bag had been taken as a central fact, the right comprehension of which would explain other facts of the same kind, but more complex. Its application to some few facts in physiology was then shown,—such as the formation of new blood-vessels; the tubular form of vessels and ducts among cells; the circulation through capillaries independently of the contraction of their coats, or of the propulsive power of the heart; and of that universal fact, that wherever there is a central heart, there are powers at work which neither its propulsive power nor capillary action can explain,—of forming new vessels in connexion with the old ones. Such a universal fact becomes a law, when the cause is shown. This cause or law, now proposed as the solution of these living processes, is, that the vital force circulating in two directions, one circle being in a plane at right angles to the other,—thus identical in direction and relation with the electro-magnetic force,—will explain the phænomena; or, in other words, that wherever there is a central moving force there is a power at work around, and to and from that centre, capable of arranging fit matter as tubes, and of circulating fluid to a certain extent through them, and that the tubular formation is owing to a vital power identical in its direction with the galvanic; and the radiated arrangement of these vessels, and the circulation (to a certain extent) of fluid through them, are dependent on a power accompanying the former, and identical in its direction with the magnetic force. The conclusion was not drawn that the vital and electro-magnetic forces were the same, but that the direction and relation of both forces were identical.

On a new Multiplying Condenser. *By* Prof. A. F. Svanberg.

The author was led by the process used by M. Pfaff of Kiel, in his researches on the electricity of contact between metals and fluids, to construct a new instrument, which, by a single contact of zinc and copper, can be charged by manipulation, requiring only a minute of time, to an intensity sufficient to give a brilliant spark and strong shock. It consists of two ordinary condensers, whose plates are of copper, the two lower connected by a copper wire. They are prevented from touching by plates of glass cemented to them, and a little larger for the sake of insulation. The lower plates are supported by insulating stems, and the upper have insulating handles. For an instance of its use, suppose the first condenser has received a small positive charge a. Raising A and touching C with the finger, D will become negative and C positive by induction. Remove the finger from C to D, the electricity of this last is retained by that of C; and at the same time replacing A, which had not lost its electricity during the preceding operations, that of B can be transported to D by a repetition of the process. By three such operations the tension of D's electricity is tripled, and this can be transferred to B by raising C and touching A. In this way it is obvious that by $3n$ manipulations the final electricity$=3^n.a$; it is easily seen that there is a certain number of transfers before changing, which gives the greatest result. Thus with two transfers and three changes $2^{12}.a=4096\,a$, while 3 (which is the best number of transfers) give with the amount of manipulation $3^8.a=6561\,a$; 4 transfers give $4^6.a=4096\,a$. Such an instrument made for the Cabinet de Physique at the University of Upsal, of six inches



diameter, gives by twenty-four manipulations a strong spark and shock felt in the elbows.

On some Results of the Magnetic Observations made at General Sir T. M. Brisbane's *Observatory, Makerstoun. By* J. A. Broun.

1st. *Magnetic Declination.*—The annual diminution of westerly declination at Makerstoun is 5′·8. When proportional parts of this have been added to the monthly means, from January 1844 till August 1846, their whole range is only 2′·1; that is to say, the mean position of the magnetic needle for any month, freed from secular change, has not been above 2′·1 further west than the mean position for any other month. Mr. Broun conceives that he has found the *annual period* of westerly declination to consist of a minimum at the vernal, and of a maximum at the autumnal equinox; the mean range being under 1′·2. From the observations for 1843, Mr. Broun has concluded that there is a maximum of westerly declination when the sun and moon are in opposition, and a minimum when they are in conjunction; that there is a maximum of westerly declination when the moon has its greatest north, and also when it has its greatest south declination, minima occurring when it crosses the equator. In the *diurnal period*, the double maximum and minimum have been found to exist in each month of the year. In the Transactions of the Royal Society of Edinburgh, Mr. Broun has given certain results relating to the horizontal and vertical components of the earth's magnetic force; but these results were obtained in scale divisions corrected for temperature by his method. In order to deduce the variations of magnetic dip and of the total magnetic force from the variations of these components, it was necessary to determine the values of the scale divisions in known units. Mr. Broun had previously shown* the inapplicability of the method given by the Committee of Physics of the Royal Society of London for the balance magnetometer. He now described a method by which the value of the micrometer divisions may be satisfactorily determined. This method will be found in the Introduction to the Makerstoun Observations for 1843. He has applied the same method to the bifilar magnetometer, and has found that the value of the scale divisions, obtained in the way recommended by the Committee of Physics, is also inaccurate for this instrument. With the aid of the values obtained by the new method, the following results have been deduced.

2nd. *Magnetic Dip.*—The dip is a minimum when the sun and moon are in conjunction, and a maximum when they are in opposition. In the mean diurnal period for the year,

The principal maximum occurs at	10^h	10^m	A.M.
„ minimum „	5	40	P.M.
A secondary maximum „	2	0	A.M.
„ minimum „	5	40	A.M.

Makerstoun mean time being always used. These periods vary to some extent throughout the year, the principal minimum occurring at 6 A.M. in winter; the two minima being nearly equal at the equinoxes, and the diurnal curve being single in summer. Mr. Broun has found that there is a maximum of dip about four hours and a half before the moon's passage of the superior meridian; a minimum about half an hour after that passage; a secondary minimum about three hours after it; and a secondary maximum about eight hours after it.

3rd. *Total force of the Earth's Magnetism.*—A minimum occurs when the sun and moon are in opposition, equal maxima near the quadratures, and a secondary minimum at the time of conjunction. In the mean diurnal period for the year,

The principal maximum occurs at	5^h	40^m	P.M.
„ minimum „	2	10	A.M.
A secondary maximum „	7	10	A.M.
„ minimum „	10	10	A.M.

The periods of maxima and minima shift about two hours in the course of the year, and in summer the principal minimum occurs at 10^h 30^m A.M. The variations of force with reference to the moon's hour angle were found by Mr. Broun as follows:—

* Transactions of the Royal Society of Edinburgh, vol. xvi.

The principal maximum occurs about two hours after the moon's passage of the inferior meridian; a secondary minimum about four hours before the passage of the superior meridian; a secondary maximum about one hour after the superior passage; and the principal minimum about six hours and a half after that passage.

Curves were exhibited illustrating these results, and also the diurnal motion of a magnetic needle freely suspended in the direction of the magnetic force. From the latter some curious results have been deduced, which will be found elsewhere. It will be enough to mention, at present, that in the mean for the year, the motion from 6 P.M. till 6 A.M. is very trifling; between midnight and 6 A.M. the needle is almost stationary, nearly the whole motion occurring between 6 A.M., Noon, and 6 P.M. The end of the needle describes an ellipse whose major axis is at right angles to the magnetic meridian; but the direction of this axis varies throughout the year.

Magnetic Causation. *By* G. TOWLER.

Magnetic phænomena are due to two distinct classes of forces, which, in the absence of more appropriate terms, may be called the "intrinsic" and "contingent." It is to the consideration of the intrinsic forces that this paper is directed. The "intrinsic" forces of the magnet are due, first, to the mechanical structure of the bodies in which magnetical phænomena are displayed, the capacity of the interstices of which bears a given ratio to the dimensions of the particle of fluid constituting atmospheric air, by and through which such interstices become highly sensitive conductors of atmospheric air; and, secondly, to the fluxion through and circulation round a magnetic bar of the particles of atmospheric media.

The following are among the propositions which the author regards as established:—

Each extremity of a magnet perpetually exercises the same power over the other that each does over indifferent masses of iron; in other words, one-half of a magnet is constantly magnetizing the other.

The "intrinsic" attribute, or *sine qua non* of a magnet, is the extreme sensibility of the fluid particles in its interstices to motion, from minute forces, arising from the mechanical conformation of magnetical substances; and the extremities, or opposite forces of the body, being within that distance of each other, whereby the forces generated by such action are sufficient to reproduce it.

On the Results of an extensive Series of Magnetic Investigations, including most of the known varieties of Steel. *By* W. PETRIE.

On the Process of Manufacture to produce permanent Magnets having the greatest fixity and capacity conjointly secured.—1st. The original iron—should be the purest soft iron *charcoal made* (not coke); the Swedish from the *Dannemora mine* is better than any other. 2nd. Converted—with pure *charcoal*; it should be carbonized *lightly*, the process to be stopped when the bars, of the usual size, are *scarcely steel through*, yet so that it will harden with certainty without an undue heat. 3rd. Sorted—with attention to homogeneous conversion, &c., according to the ordinary rules. 4th. Melted—the pot kept covered, and not longer than necessary in fusion. 5th. Cast—into a large ingot, so as to allow of its being *well* rolled out singly, before it becomes reduced to the requisite thinness. 6th. Rolled—while hot from casting, to save a second heating. It should not be doubled over nor sheared and faggoted. The rolling should be conducted at as low a temperature as convenient, as it thereby acquires a harder and closer texture and finer grain. 7th. In cutting—into shape, the substance (if large or of varied form) should not be strained, as by boring with *rimers*, or straightening (oftener than is unavoidable) with the hammer, as it is then apt to warp and to have unseen commencements of cracks on becoming subsequently hardened.

More carbonization than that previously described as best is of little injury to the magnetic goodness of the steel, provided it be so prepared as to preserve a homogeneous and *white* appearance of fracture when hardened, which is not so easily managed as with that of lower carbonization; but if it be again carbonized *more* than usual (as razor steel, or above that) it rather improves; and again, an increase deteriorates it as in cast iron, and a further increase again improves it. In short, *in the*

scale of carbonization there is a succession of continually decreasing maxima of advantage.

On the Physical Properties which the Steel should possess.—The fineness of grain is affected by many adventitious circumstances, which must be considered and allowed for in judging of it; and the most important fact is the difference between the appearance in the *hard* and *soft* states; for in the general properties, both optical, mechanical and magnetical, their order, in any set of samples, is *reversed* in the hard state, independently of the absolute change in each property.

The steels should be examined by breaking with a *single* bend at a file notch (notching with a chisel, bending back, &c. changes the appearance). A microscope of six or ten lineal power is better than any other power for examining it.

The *general* properties, without going into detailed description, should be as follows, the terms being comparative with other samples of less value, and not at all with the hard or soft states of the same steel.

IN A SOFT STATE.	IN A HARD STATE.
General appearance, uniform darkish gray ...	Uniform white.
Rather a large grain, compared with razor steel (or finer if much rolled).	A smaller grain than it was before.
Rather irregular in size and shape of grain, unless fine	Rather more regular than before; *rounded* crystallization disappears.
Rounded crystallization	Grains individually distinct with good metallic lustre.
Close texture without cavities	Not particularly close.
Rather tough for steel	Brittle and very hard.
Attracted considerably before magnetizing ...	Ditto.
Loses induced magnetism more freely than other steels	Retains magnetism well and abundantly.

Care must be taken to discriminate between real cavities and indentations arising from the crystals being torn up by the breaking; pure iron often appears porous from this cause.

The author added some peculiar considerations on the chemical constitution and molecular arrangement of certain sorts of steel; and on the molecular peculiarities of iron and other metals, in connexion with their magnetic capacity, illustrated by a tabular arrangement.

On Hardening, &c.—In the ordinary process there is much risk and difficulty for large work, owing to unequal heat, unnecessary time and heat applied, especially to fine edges, decarbonization, scaling, &c.

These are obviated by a process, which is new as applied on a large scale, namely, heating in melted lead. It will be observed that the *precise* heat is imparted *quite* uniformly in half a minute or so, and the finest edge is heated momentarily no higher than the thickest part (rendering this process incomparable for all instruments where it is the edge or smaller parts that are of importance). *No scale* is formed, the finest polish or sharpest edge being preserved through the hardening; the previous preparation of the steel and some other points are described; and particularly the manner of refrigeration in water (salt), and for securing hardness and great evenness, are also detailed.

The process has been applied to steel sheets of 10 inches by 20, obtained quite flat, and as hard as a file throughout, even at the middle parts, which has hitherto been found very difficult, we may say impossible. Magnets prepared by these means only differ generally in magnetic power by $\frac{1}{10}$th part, many being absolutely equal.

Particulars are then given of the advantage of certain high powers for magnetizing bars, and of an apparatus constructed weighing 2 cwt. and possessing nearly as great aggregate power as the colossal magnet in possession of the Royal Society (weighing we believe 2 tons).

A method is suggested for verifying the constancy of magneto-meteorologic instruments, by means of the terrestrial magnetism itself; independently of its own variations, or of the comparison of the mutual action of three or more bars.

On the Mode of Developing the Magnetic Condition. *By the* Rev. W. Scoresby, *D.D., F.R.S.*

Dr. Scoresby stated that he had, at York, shown a new and superior mode of developing the magnetic condition in properly prepared and hardened steel bars, by interposing a thin plate of soft iron between the operating magnet and the bar of steel to be magnetized. He had, at that time, supposed it to be necessary to extend the thin plate of soft iron the entire length of the bars of steel to be magnetized. But he had since found this to be by no means the case; since by laying any number of unmagnetized bars of steel in a long line, and passing along them a horse-shoe magnet with its poles connected with a thin polished plate of soft iron (he used common hoop iron), the ends being slightly bent upwards to cause it to pass more freely over the steel bars, and then turning them over and renewing the process on the other face, he found he could communicate to the bars the full charge which they were competent to receive. The author exhibited this experiment: and by simply passing a horse-shoe magnet thus armed with an interposed piece of sheet iron, once over each face of twelve previously unmagnetized bars of steel, he communicated to them so much power as that they sustained their own weight, when held up as a chain.

On the Constitution and Forces of the Molecules of Matter. *By* Dr. Laming.

In this paper the author applied a theory of the molecular constitution of matter in forty-two distinct propositions to the explanation of gravitation, temperature and specific heats of gases, cohesion, affinities, latent heat, volume, disturbances of electrical equilibrium, and other electrical phænomena, with electro-motion and electro-chemical decomposition. In this theory, matter is regarded as constituted of atoms; each of which consists of three sorts of spherical atoms, distinguished as *basic, calorific,* and *electrical.* The only force it recognizes is *attraction.* The basic atoms do not attract one another, neither do the calorific; but the electrical attract each other with a force reciprocally as the square of their distances. Each electrical atom attracts calorific atoms around it, and each basic atom attracts calorific in unlimited numbers; whilst it also attracts around it electrical atoms, in some large but definite number. This number is in each case unchangeable, but the basic atoms differ one from another in attracting around them a greater or less number of electrical atoms. The force between basic and electrical atoms is much greater than that between the electrical atoms mutually; hence one of these is termed the major, the other the minor electrical force. The attraction of the basic for the calorific atoms is intermediate between these. The attraction of the electrical for the calorific atoms is the greatest of all the mutual forces. The immediate consequence of these forces is to cause each electrical atom to be surrounded by calorific atoms, and each basic atom to be then enveloped with these electrical atoms, in greater or less number according to its chemical nature, but in each case definite. One of these basic atoms so surrounded is the elementary molecule of matter, or the simple atom of the chemist. Each basic atom thus surrounded by its sphere of electrical atoms constitutes an *electrosphere*; but a change of the calorific atomospheres of the electrical atoms of this, may cause a change of their arrangements about the central basic atoms, so that some of the electrical atoms may be thrown out on the surface of the electrosphere and thus become *complementary*; and it is upon the mutual actions and relations of these complementary atoms that all electrical and other phænomena involving change are supposed to depend. One remarkable consequence of this theory is, that gravitation depends on the electrical atoms alone; and that hence a positively electrified body must be heavier, and a negatively electrified body lighter, than the same body with its electricity in the ordinary undisturbed state. This the author proposed to prove experimentally to the Section.

On Atmospheric Waves. *By* W. R. Birt.

In introducing his report, the author noticed the steps he had taken during the last autumn for observing the great symmetrical wave of November. Instructions detailing the instruments to be observed, times of observation, &c., were drawn up and forwarded by him to gentlemen interested in meteorological research, and also other-

wise circulated*. In accordance with these instructions, about thirty sets of interesting and valuable observations had been made; the stations extending in one direction from the west of Ireland to Heligoland, and in the other from the Scilly Isles to the Orkneys. These observations Mr. Birt had subjected to a very careful comparison, especially those made at his own residence near London, with those which he made in the autumn of 1842 at Leicester Square. The result of this comparison was such as clearly to show that there was a most striking coincidence between the barometric movements of October and November 1845, and those of a portion of September, October and November 1842. So close did this coincidence appear to the author, that during the period from October 1 to November 21 in 1845, the barometric movements of October 23 to 26 were the only oscillations that appeared to have no corresponding movements in 1842. It appeared that the great wave commenced in 1845, near midnight, between the 6th and 7th, that it culminated on the 14th, and terminated on the 21st; during the 10½ days previous to the setting in of the wave, the movements in 1842 and 1845 were almost identical. Mr. Birt observed that in 1845 the great wave, in all its essential features, was very distinctly marked; that it was completely separated from all the preceding barometric movements, and that the *individuality* that was thus given to it, induced the strong belief that we have obtained the *type* of the barometric oscillations during the middle portion of November. This type he proposed to express in the following language:—

"That during fourteen days in November, more or less equally disposed about the middle of the month, the oscillations of the barometer exhibit a remarkably symmetrical character, that is to say, the fall succeeding the transit of the maximum or highest reading, is to a great extent similar to the preceding rise; this rise and fall is not continuous or unbroken; in three out of four of the occasions on which it has been observed, it has been found to consist of *five* distinct elevations. The complete rise and fall has been termed the great symmetrical barometric wave of November, and as such has been considered to result from the transit of a large wave, but there is great reason to believe that while it may be due to the transit of a normal wave of about fourteen days' amplitude, it also exhibits the transits of *five* secondary superposed waves. At the setting in of the great November wave the barometer is generally *low*, sometimes below 29 inches. This depression is succeeded by *two* well-marked undulations, varying from one to two days in duration. The central undulation, which also forms the apex of the great wave, is of larger extent and longer duration, occupying from three to five days; when this has passed, two smaller undulations, corresponding to those at the commencement of the wave, make their appearance, and at the close of the last the wave terminates."

Mr. Birt exhibited curves of observations that had been made during November at Dublin, from 1829 to 1845 inclusive, which he had received from Capt. Larcom of the Royal Engineers. From these curves, it appeared that the great wave had been observed at Dublin in twelve out of seventeen years, and that with two exceptions in eleven years of distinct and well-marked transits of the great wave, the epochs of the maxima were confined to five days, near the *middle* of the month, namely from the 12th to the 17th†.

The author then proceeded to notice the comparison he had instituted between the curves he had obtained from various stations, and exhibited curves from twelve stations in Ireland, England and Heligoland. From a consideration of these curves (which were so arranged as to show the departure from symmetry in certain directions), he argued that while the posterior slope of a wave of considerable magnitude was passing off towards the E.N.E., the front of another was approaching from the N.W., and that it was the interference of the two that produced the symmetrical arrangement of the curves. In that portion of the area covered by the advancing wave the barometer rose; in that covered by the receding wave it fell; while in that in which the two waves interfered, the atmosphere as regarded these waves was quiescent, and the smaller secondary waves passed on uninfluenced by them. He also showed that

* These instructions, with a short notice of the wave, were published in the Athenæum of Sept. 6, 1845. No. 932, pp. 880, 881.

† While exhibiting these curves, the author invited the attention of the Section to a very remarkable and apparently constant depression of the mercurial column which occurred about the 28th of November. It had been observed in fifteen out of the seventeen years' observations, and appeared [illegible]ed with the great wave.

these lines of symmetry or interference varied in different years; in the year 1842 the line of greatest symmetry passed from Dublin through Brussels to Munich; in 1845 it appeared to be confined to the south of England.

Mr. Birt next proceeded to notice the arrangements of the aërial currents or winds with regard to the distribution of pressure. He stated that the observations on the winds in November 1842, clearly established Prof. Dove's theory of parallel and oppositely directed currents, and he showed by diagrams that if these currents are shifting ones, as the Professor suggests, as they passed over any tract of country in a direction transverse to those in which the wind was blowing in each, all the phænomena of an atmospheric wave would be produced. He remarked that if there was only one set of these parallel currents passing over a line of country, then the examination of the phænomena of an atmospheric wave would be comparatively easy. The discussion of the observations had however shown that there were two sets of parallel and oppositely directed currents at right angles to each other, one set from the N.E. and S.W., with a lateral motion from the N.W., and the other from N.W. and S.E., with a lateral motion from the S.W.; and also that when these currents are referred to the wave, the N.E. and N.W. currents, in their respective systems, represent anterior slopes with the direction of the aërial currents at right angles to the axis of translation directed towards the *left-hand*; and the S.W. and S.E. currents represent posterior slopes, the direction of the aërial currents still at right angles to the axis of translation, but directed towards the *right-hand**. The author considered that these rectangularly posited currents explained several phænomena, such as the barometric wind-rose, the revolution of the vane in one uniform direction, &c., and concluded his report with pointing out several important desiderata that it was desirable should be made the subjects of future inquiries.

CHEMISTRY.

On the Changes which Mercury sometimes suffers in Glass Vessels hermetically sealed. *By* Prof. Oersted.

It has been frequently noticed that mercury inclosed in glass tubes, even when those tubes were hermetically sealed, undergoes a remarkable change. It first becomes covered by a thin film of a yellow colour, which adheres to the glass, and becomes eventually nearly black. This has been attributed to oxidation, but the oxidation which would arise from the exceedingly small quantity of atmospheric air which could be contained within the bulbs exhibited by Professor Oersted was too small to account for the formation of such a quantity of dark and yellow powder as many of them exhibited. Professor Oersted referred the change on the mercury to the action of that metal on the glass of which the bulb was formed. It appears that sulphate of soda is frequently employed in the manufacture of glass, and it is thought that a sulphuret of mercury is formed by the decomposition of the glass itself. This is not however satisfactorily proved, and the subject has only been brought forward that attention might be directed to a subject which appeared to involve some remarkable conditions.

On a second new Metal, Pelopium, contained in the Bavarian Tantalite. *By* Prof. H. Rose.

In a former communication it had been shown that the so-called tantalic acid which occurs in the Bodenmais in Bavaria, consisted of two acids, one of which differed materially from all known acids. To this Professor Rose gave the name of Niobium, regarding it as a new metallic oxide. After a most elaborate investigation, Professor Rose has found that the other acid contains another oxide of a metal dif-

* These directions are in close accordance with that of the rotation of the air in revolving storms, and appear strongly to support Sir John Herschel's suggestion, *that such storms may be produced by the crossing of two large atmospheric waves moving in different directions.* See Sir John's Report on Meteorological Reductions, Report, 1843, p. 100.

fering from niobium, and to this metal he has given the name of Pelopium, from Pelops the son of Tantalus and the brother of Niobe. The tantalite of Bavaria is therefore now shown to contain three metals—tantalium, niobium and pelopium. These differ from each other in specific gravity, and they exhibit different and peculiar chemical properties.

On Cavendish's *Experiment respecting the production of Nitric Acid.* *By* Prof. Daubeny, *M.D.*, *F.R.S.*

Dr. Daubeny stated the result of some experiments he had instituted with the view of ascertaining whether the production of nitric acid by electricity, as was first effected by Cavendish, really arose from the *direct* union of oxygen with nitrogen, or was produced *indirectly* through the presence of minute portions of ammonia. For this purpose he deprived the air, through which the electrical sparks were to be passed, of water, and of any traces of ammonia that might have been contained in it, by allowing it to stand in contact with concentrated sulphuric acid for some time previous to the commencement of the experiment. Even in this case, although the air had been in contact with no liquid except the mercury over which it was confined, the usual diminution of volume took place after the electrical sparks had been passed through it, and solution of litmus, when introduced into the tube, became sensibly reddened. Hence the author infers that nitrogen does combine *directly* with oxygen, as it is now known to do with carbon, but he still questions whether it can do so with gaseous hydrogen, since ammonia cannot be formed, as nitric acid is, by means of electricity; and, as in all the cases in which ammonia has been produced artificially, one of the elements appears to have existed in what is called a nascent state. But if nitrogen can be made to combine directly with oxygen, how comes it that through the operation of thunder-storms the composition of the whole atmosphere has not before this time been changed by the production in it of considerable quantities of nitric acid? This the author explains by the small amount of heat generated by the union of the two gases, owing to which only those particles combine which lie contiguous to *the line of the electrical spark*; whereas in other cases, as in that of the union of oxygen with hydrogen, so much heat is elicited by the union of those particles which are affected by the passage of the electrical spark, that a condensation of other portions of the mixture results, whence will arise a union of more of the particles, and an extrication of a larger amount of heat. In this way the explosion propagates itself through all parts of the mixture with a rapidity which causes it to be considered by us as instantaneous. In all cases however in which gaseous elements that can remain together without acting upon each other are made to unite, the *modus operandi*, whether it be by electricity, by heat, or (as in the case of porous bodies) by adhesive affinity, appears to be the same, that is, such a condensation of the respective gases as shall bring their particles within the sphere of their mutual affinity.

On the extent to which Fluoride of Calcium is soluble in Water at 60° F. *By* George Wilson, *M.D.*

In April of this year, 1846, Dr. Wilson read a paper to the Royal Society of Edinburgh announcing the solubility of fluoride of calcium in water, and stating that in consequence of observing this fact, he had been led to seek for that salt in milk, in blood, and in sea-water, where it had not been previously detected, but in all of which he found it. He also mentioned that he was able to confirm the results of previous observers as to the presence of fluoride of calcium in natural waters, in plants and in animal remains, as well as in the urine of man.

Since that paper was read, Dr. Wilson ascertained the extent to which fluoride of calcium is soluble in water at 60° F.; and as it is a point of some interest in connexion with geological and mineralogical, as well as with chemical speculations, he brought it before the Chemical Section of the Association. The experiments recorded below were performed with a solution of native well-crystallized fluor spar, prepared by boiling distilled water upon the powdered fluor, which had been previously purified by digestion with warm aqua regia, so as to remove any trace of metallic oxides, lime-salts or the like, which might be present. The solution at 212° F. was filtered

whilst warm, and left at rest for some days in stoppered bottles at a temperature of about 60°, till it deposited the excess of fluor soluble above that temperature. It was then filtered a second time. A certain volume of the solution measured at 60° was evaporated to dryness on the vapour-bath, in a counterpoised platina basin, and the weight of the residue ascertained.

Twenty-four pints of the solution were thus made use of. In six experiments, one imperial pint of the solution (16 fluid ounces, or 7000 grains) was taken at each trial. In four trials three pints were evaporated at each experiment. In one case six pints were employed. The following are the results :—

				Per pint.	
Expt. I.	evap. 1 pint of	solution.	Residue	0·27 grs.	
II.	,,	,,	,,	0·28	
III.	,,	,,	,,	0·28	
IV.	,,	,,	,,	0·24	
V.	,,	,,	,,	0·27	
VI.	,,	,,	,,	0·25	Average 0·265 per pint.
				Per pint.	
Expt. VII.	evap. 3 pints of	solution.	Residue	0·79 = 0·263	
VIII.	,,	,,	,,	0·78 = 0·260	
IX.	,,	,,	,,	0·78 = 0·260	
X.	,,	,,	,,	0·77 = 0·257	Average 0·260 per pint.
				Per pint.	
Expt. XI.	evap. 6 pints of	solution.	Residue	1·62 = 0·27	Average 0·270 per pint.

Twenty-four pints of distilled water thus dissolved 6·330 grains of fluor spar; so that the average amount dissolved in one pint will be 0·2637 grains. One grain therefore of fluor will requrie 26·545 grains of water at 60° F. to dissolve it, or water at that temperature will take up $\frac{1}{26{\cdot}545}$ths of its weight of the salt.

The solubility here indicated must be considered great for a salt hitherto reputed quite insoluble. It is still more soluble in water at a high temperature, as the deposit left by warm solutions on cooling shows. These facts will now be connected with the appearance of fluoride of calcium in plants and animals, as well as in mineral veins and elsewhere, and may perhaps prove sufficient to explain these hitherto perplexing phænomena.

Analysis of the American Mineral Nemalite. *By* Prof. CONNELL, *F.R.S.E.*

This mineral bears a striking resemblance to asbestus, so that by the eye it can hardly be distinguished from it. It was first chemically examined by Mr. Nuttal, who ascertained that it differs entirely in constitution from asbestus, and concluded from his experiments that it consists essentially of magnesia and water with a little oxide of iron and lime. It was subsequently examined by Dr. Thomson, according to whom it also contains 12½ per cent. of silica. The constituents found by the latter were—

Magnesia	51·721
Silica	12·568
Peroxide of iron	5·874
Water	29·666
	99·829

The result which I have obtained differs somewhat from both the preceding. According to both the previous experimenters, the mineral is soluble in acids without effervescence. But I have found that even perfectly fresh portions of the specimens (which I have) of the mineral from Hoboken in America sensibly effervesce when dissolved in acids, showing some carbonic acid to be contained in it. I have also found only a very minute quantity of silica, the mineral leaving scarcely any residue when dissolved.

The amount of water was determined by ascertaining the quantity of water collected by ignition in a tube of German glass twice bent, and containing at one end

fused chloride of calcium. The carbonic acid was estimated by the loss of weight on treating a portion of the mineral with dilute acid in a little bottle connected with a tube containing chloride of calcium.

The solid constituents were determined by ordinary methods. The result was, in 100 parts,—

Magnesia	57·86
Protoxide of iron	2·84
Silica	0·80
Water	27·96
Carbonic acid	10·00
	99·46

Considering the protoxide of iron to replace a little magnesia, the mineral appears to be a combination of hydrate of magnesia and hydrated carbonate of magnesia. The formula $5MgO, HO + MgO, CO^2, HO$ will nearly express its constitution, and gives—

Magnesia	61·67
Water	27·24
Carbonic acid	11·09
	100·00

The native hydrated carbonate of zinc (zinkblüthe) is a mineral of analogous constitution.

Observations on the Nature of Lampic Acid. *By* Prof. Connell, *F.R.S.E.*

The author had shown some years since that a large quantity of formic acid and a little acetic acid exist in lampic acid as prepared in the ordinary way. Marchand and others, admitting the presence of these acids, maintain that in addition it contains aldehydic acid. It appears however to Professor Connell that the mere reduction of oxide of silver without effervescence, the formation of resin with alkaline solutions, the blackening of the lampic salts on evaporation and by the action of sulphuric acid, are insufficient to support this view; and these facts are all explained on the idea of aldehyde being associated with the acetic acid present in the liquid. Further, the atomic weight of lampic acid, 50·35, is much too high to belong to an acid, containing aldehydic acid, associated with much formic acid. But if we suppose a foreign body, such as aldehyde, associated with the acetic portion of the liquid, and entering for the time into the constitution of its salts, we can easily explain the high atomic weight and chemical reactions.

On the Connexion between the Isomorphous Relations of the Elements and their Physiological Action. *By* James Blake, *M.B., F.R.C.S.*

In a paper read before the Academy of Sciences at Paris, the author remarked "that when introduced directly into the blood, the salts of the same base appear to exert the same effect on the animal œconomy." Since that time further researches have led to the discovery of a law, equally interesting under a chemical as under a physiological point of view. The law alluded to is that, when introduced into the blood, all isomorphous substances produce analogous effects and give rise to the same reactions in the animal œconomy. This law has been verified by an extended series of experiments with the salts of magnesia, lime, manganese, iron, cobalt, nickel, zinc, cadmium, copper, bismuth, lead, baryta, strontia, soda, silver, potash, ammonia, palladium, platinum, osmium, iridium, antimony,—the acids of phosphorus, arsenic, bromine, chlorine, iodine, sulphur, and selenium. One of the facts observed is the connexion which exists between the physiological action of these substances, and their isomorphous relations to the elements of the blood. It is found that those substances which exist in the blood, or which have isomorphous relations with its elements, give rise to the least marked reactions: thus phosphoric and arsenic acids can be introduced into the veins without producing any marked phænomena, whilst, on the other hand, those elements which are most distinct in an isomorphous point

of view, from the constituents of the blood, are those which give rise to the most marked phænomena. Two drachms of arsenic acid injected into the veins will produce no marked effect on any organ; but a grain of chloride of palladium, or two grains of nitrate of baryta, are sufficient instantly to arrest the movements of the heart. Several other instances analogous to those quoted were pointed out.

On the Action of Oxalic Acid upon the Dead Tissues of the Animal Body. *By* H. LETHEBY, *M.B.*

It has been stated by Dr. Coindet, Dr. Christison and others, that oxalic acid does not appear to have any corrosive action on the stomach like the mineral acids. Dr. Letheby however remarks that these statements are opposed to the observations which he has made. In every case which he had examined of poisoning by oxalic acid, the stomach soon after death was found to be completely corroded, so that it would scarcely hold together. Numerous experiments were made with various animal tissues, such as submitting skin, stomach, intestine, muscle and tendon to the action of solutions of oxalic acid of different strengths. After standing about twelve or fourteen hours at a temperature of 60° Fahr., it was found that the cellular and mucous tissues of each underwent either complete solution, or else were so softened that they broke down under the pressure of the thumb and fingers; the albuminous and muscular tissues were also softened and looked as if they had been scalded.

On an important Chemical Law in the Nutrition of Animals. *By* R. D. THOMSON, *M.D.*

This paper was a recapitulation of the results obtained by Dr. Thomson when engaged on the Government Commission, and published in the Report presented to Parliament, and also in Dr. Thomson's 'Researches on the Food of Animals.'

On the Difference in the Physiological Actions of the Yellow and Red Prussiates as an evidence of their containing dissimilar Radicals. *By* H. LETHEBY, *M.B.*

In the course of his inquiries into the actions of the various compounds containing cyanogen on the animal œconomy, the author was particularly struck with the great dissimilarity in the effects produced by the yellow and red prussiates of potash, and was led to think it might furnish some evidence upon the side of Liebig's doctrine, that the two salts contain radicals which are dissimilar. To prepare himself for this inquiry, however, he thought it necessary to ascertain what would be the effects of the simple and the double cyanides, and then to experiment with the yellow and red prussiates of similar bases. Of the simple cyanides, he chose those of potassium, sodium, ammonium, mercury, lead, iron, zinc and silver; and, to provide against any fallacy which might arise from the action of the gastric juice, injected them into the veins or peritoneal cavity. Contrary rather to his expectations, it was found that they were all poisonous; the soluble ones generally acting as quickly as prussic acid, while the others required a little longer time for the development of the symptoms; but in all cases death followed their administration, from two to five grains being sufficient to produce such a result. Of the double cyanides, he chose those of potassium and zinc, potassium and silver, potassium and nickel, and a mixture of cyanide of potassium with cyanide of iron. These also were found to be most poisonous, proving fatal in doses almost as small as the preceding. Now, these inquiries clearly established two facts,—that neither the simple nor double cyanides could be given even in five-grain doses with impunity. The author was therefore much astonished to find that a class of salts regarded by some chemists as double cyanides should have little or no action upon the animal œconomy, and that they might be administered in doses of half an ounce without their exhibiting any unpleasant symptoms whatever. This was found to be the case with the ferrocyanide- experiments having been made with those of potassium, sodium, ammonium, bari lead, iron and silver.

He next examined the effects of the red prussiates; and here again, contrary to what would have been surmised from the want of action in the preceding compounds, it was found that they constituted a class almost as poisonous as the simple cyanides. The experiments were made with the red prussiates of potash and lead, and with a crystalline acid obtained by the action of muriatic acid and æther upon the former of these compounds. Each of them was quickly fatal in doses of from ten to forty grains.

On the use of stating, with the results of Analyses, the nature of the Methods employed. *By* W. West, *F.R.S.*

The author of this communication pointed out the necessity which existed for knowing, not merely the results to which chemists might arrive, but the processes by which these results were obtained. It was shown that many of the discrepancies found to exist in analytical results would thus be satisfactorily explained, and all doubt as to the correctness of an analysis removed.

On the presence of Atmospheric Air, uncombined Chlorine, and Carbonic Acid found in the Water of some of the Wells in the suburbs of Southampton, and their Action on Lead. *By* Henry Osborn.

The principal object of this paper was to caution persons residing in the neighbourhood of Southampton against the use of leaden pipes for conveying water, and to induce them to avoid the use of lead in any form for that purpose without having the water previously examined, in order to ascertain whether it possessed the property of acting upon the metal and holding it in solution. The author brought forward several instances of the serious consequences which had resulted from the use of water impregnated with lead, and pointed out the different solvent principles found in the water, one of which was uncombined chlorine discovered in a spring in the New Forest. This water possessed the property of bleaching Brazil paper and reddening litmus paper after concentration. The amount of uncombined chlorine was estimated as chloride of silver by deducting the amount of the latter contained in twenty ounces of water from that of the chlorine contained in the solid contents, the former weighing 1·2 more than the latter; thus indicating 0·296 of uncombined chlorine which is capable of uniting with 0·864 of lead, forming 1·16 of chloride of lead in the imperial pint. The lead held in solution by carbonic acid and the oxygen of atmospheric air was converted into chromate of lead, and estimated as chloride of lead, which indicated 0·25 or 0·2 of the oxide in twenty ounces of water. The solid contents in an imperial pint were found to vary from one to three grains, and to be composed of the chlorides of sodium, calcium and magnesia, sulphate of lime, silica and vegetable matter. Notwithstanding the preservative property which the salts contained in spring-water are said to possess by forming an insoluble crust in the interior of the pipes, it was found that the leaden pipes had been in use for some years and the action of the water on the lead still continued with as much energy as when they were first laid down, thus showing the presence of the above solvents, and that they met with no resistance from the presence of the saline matter.

On the Rationale of certain Practices employed in Agriculture. *By* Prof. Daubeny, *M.D., F.R.S.*

The Professor instanced among other practices the use of quicklime and of gypsum as fertilizers to the land.

The former of these substances he supposes to act in part by rendering those inorganic substances which are present in the soil more soluble, or, in accordance with the views laid down by the author in a memoir which he has published in the Philosophical Transactions of last year, by converting the *dormant* constituents of the soil into *active* ones, or into a state in which they become immediately available.

He appealed to the authority of Professor Fuchs, confirmed by that of Mr. Prideaux of Plymouth, as showing that the alkali may be extracted from granite readily by water after the rock in a pounded form has been heated together with quicklime;

and he stated that a soil exhausted by long-continued cropping was found by himself to yield to water twice as much alkali, after having been mixed with quicklime, as it had done before.

Hence the frequent application of lime tends to produce exhaustion in the land, not only because it supplies in itself no fresh alkali, but likewise because, by rendering that which the soil contains more soluble, it causes it to be washed away more readily by atmospheric water.

Ploughing, and other mechanical methods of pulverizing the soil, appear to act in the same way; and so also may we suppose to do the sprinkling of the soil with sulphuric acid, as is practised in some parts of the continent.

The author then alluded to the various modes of explaining the advantage attributed to gypsum which certain leading agricultural chemists had proposed; one ascribing its virtues to the direct influence of the salt; another to the indirect good resulting from it, owing to its property of fixing ammonia; a third regarding its acid constituent as of the principal utility; and a fourth its base.

Dr. Daubeny gave reasons for rejecting the third and fourth of these hypotheses, but considered that the use of gypsum may be in part attributable to the *first* and in part to the *second* of the causes pointed out; supposing that this substance is *generally* useful to *all* plants from its property of fixing ammonia, and also *especially* serviceable to certain species, by supplying them with a salt which they require for their development. He was principally anxious however to bring forward this subject, in the hope of inducing chemists to institute fresh experiments for the purpose of setting the question at rest.

On the Fairy-rings of Pastures. *By* Prof. J. T. Way.

A description of these patches, with which most persons are familiar, was given; and it was stated that the grass of which such rings are formed is always the first to vegetate in the spring, and keeps the lead of the ordinary grass of the pastures till the period of cutting. If the grass of these fairy-rings be examined in the spring and early summer, it will be found to conceal a number of agarics or "toad-stools" of various sizes. They are found situated either entirely on the outside of the ring or on the outer border of the grass which composes it. The theory of DeCandolle, that these rings increase by the excretions of these fungi, being favourable for the growth of grass but injurious to their own subsequent development on the same spot, was remarked on, and shown to be insufficient to explain the phænomena. A chemical examination of some fungi (the true St. George's Agaric of Clusius—*Agaricus graveolens*) which grew in the fairy-rings on the pasture around the College at Cirencester was made. They contained 87·46 per cent. of water, and 12·54 per cent. of dry matter. The ashes of these were found to contain—

Silica	1·09
Lime	1·35
Magnesia	2·20
Peroxide of iron	trace
Sulphuric acid	1·93
Carbonic acid	3·80
Phosphoric acid	29·49
Potash	55·10
Soda	3·32
Chloride of sodium	0·41
	98·69

The abundance of phosphoric acid and potash, existing no doubt as the tribasic phosphate of potash (3KO, PO5), which is found in these ashes is most remarkable. The author's view of the formation of these rings is as follows:—A fungus is developed on a single spot of ground, sheds its seed and dies: on the spot where it grew it leaves a valuable manuring of phosphoric acid and alkalies, some magnesia, and a little sulphate of lime. Another fungus might undoubtedly grow on the same spot again; but upon the death of the first the ground becomes occupied by a vigorous crop of grass, rising like a Phœnix on the ashes of its predecessors. It would thus

appear that the increase of these fairy-rings is due to the large quantity of phosphated alkali, magnesia, &c. secreted by these fungi; and whilst they are extending themselves in search of the additional food which they require, they leave, on decaying, a most abundant crop of nutriment for the grass.

On certain Principles which obtain in the application of Manures. By WILLIAM CHARLES SPOONER.

This was a paper by a practical agriculturist, who has paid attention to the recommendations of chemists as to the application of manures. It was pointed out that many of the recommendations of chemists were nearly valueless to the practical farmer on account of the expense involved in their employment. The direct application of sulphuric acid and silicate of potash were adduced as examples, the expense in both cases rendering their use impracticable, however valuable these ingredients may otherwise prove. Many other examples were given enforcing on chemists the necessity of connecting with their experimental inquiries the practicability of their agricultural applications, both with reference to economical use and the ease with which they may be employed.

On the application of the Principles of a Natural System of Organic Chemistry to the Explanation of the Phænomena occurring in the diseased Potato Tuber. By G. KEMP, *M.D.*

At the meeting of the Association last year at Cambridge, Dr. Kemp introduced to the notice of the Society an outline of the results of two years' investigation into the nature of the changes effected by vital and physical agents on organized bodies, his principal aim being to suggest an arrangement founded upon natural affinities, and capable of interpreting the results of organic analysis, consistently with the phænomena which natural or artificial agents have effected.

At an early period of the ravages committed last year by what is called the potato disease, Dr. Kemp was induced, by the application of elementary analysis, to attempt the removal of some of the difficulties in which the explanation of the subject was involved. The results of those analyses are recorded in the abstracts of the Cambridge Philosophical Society. By the application of the principles of the natural system of organic chemistry which he has suggested, the author arrived at the conclusion, "that the true nature of the affection is an *abnormal tendency to premature germination*," and that the changes which the diseased tuber undergoes are identical with those which had three years previously been discovered by Erdmann, Marchand and Scharling to take place during the normal germination of seeds and tubers.

Some remarks followed which all bore on the importance of autumn planting. Numerous striking instances were adduced in which healthy potatoes had been grown from diseased tubers planted in the autumn.

Some Inquiries into the Extent, Causes and Remedies of Fungi destructive in Agriculture. By J. PRIDEAUX.

1st. *Extent.*—DeCandolle's theory of injurious excretions having been opposed by many arguments and experiments, particularly those recently published by Dr. Daubeny; that of Liebig, of specific exhaustion of the soil by plants of one species, leaving it fit for another which required different ingredients, had been generally substituted. Some however had taken a middle course, and supposed plants to breed animalcules; which they left in the soil, and which would feed upon other plants of the same species, but not upon those of different ones. The writer also, unsatisfied with the theory of specific exhaustion of inorganic ingredients, from the occasional unaccountable efficacy of ashes and soot, and the inconsistent effects of inorganic manures; had investigated the organic residues on the soil,—after wheat, barley, turnips and potatoes; compared them with the premature decay of wheat (where too often cultivated) in patches, expanding from centres, like fairy-rings; and with the notoriety of fungus in the potato disease; and had thence been led to inquire how far such fr[illegible] might be the general representatives of DeCandolle's sup-

posed injurious excretions. To what extent this may be true, the microscope will best decide, by examining the roots and contiguous soil of plants after harvest, especially those which have ripened seeds.

2nd. *Causes.*—Fungi and mucors were supposed to bear somewhat the same relation to vegetable, as mites and the like to animal, life—a sort of debased or degraded vitality, produced when the organizing vital power was not enough predominant over the disorganizing tendency to decomposition, to effect due assimilation of the nutritious matter presented; but still sufficiently so to prevent decomposition or decay. The constant struggle between the organizing vital force, and the decomposing power of chemistry, was described; and instances were adduced to show that the invigoration of the vital force by solar light, and abundance of proper nourishment, enabled it effectually to repress the decomposing action; whilst, on the contrary, gloom, warm damp, and stagnant electrical air, assisted the disorganizing force, and often produced predatory fungi, which might thus be considered a sort of retarded disorganization. So ripening plants, as their vital powers decay, might generate such parasites, which would explain how they weaken the soil so much more than green crops, in proportion to the contents of their ashes. Such fungi, though not the cause of disease or decay, are effeetual promoters of both, and probably the *chief* means of infection, where that also exists.

3rd. *Remedies.*—If further investigation prove fungi thus generated to produce such generally injurious effects, the remedies will be of practical importance. These should be cheap and antiseptic, as well as destructive to fungi. Sulphate of copper with salt, which had been successfully used for seed potatoes, was too costly for spreading over the soil. Fresh lime, the general destroyer of noxious vermin, roots and seeds, would probably answer till rendered inert by carbonic acid. Salt, which appeared more promising, he had found, in some experiments, rather promote than destroy fungi. Lime and salt digested together would eliminate caustic soda, a very active destroyer; and soda ash, with or without lime, would have a somewhat like effect; and ammoniacal gas liquor is perhaps a still more destructive application. But none of these alkalies can be regarded as antiseptic; and the ammonia, when neutralized in the soil, might even promote disorganizing fermentation where already too strong; and therefore, though they might do after seed crops, more antiseptic dressings must be used where there is putrescent tendency. Chloride of lime, in solution, he had found useless on diseased potatoes; the powder had been said to answer better, but either would soon be rendered inactive in the soil by the humous matters. Sulphuric acid, diluted, might succeed, where farmers had the means of applying it; and alum, which is of easy application, is a cheap and powerful antiseptic.

Dressings of this kind, intended to kill the fungi and check the disorganizing action, would be turned under in the first ploughing after harvest, independent of the usual manure for nourishing and exciting vital action.

New Facts bearing on the Chemical Theory of Volcanoes.
By Prof. DAUBENY, *M.D., F.R.S.*

This communication detailed the views formerly promulgated by the author in support of that at one time entertained by Sir Humphry Davy, that volcanic phænomena are due to the oxidation of the metallic bases of the earths and alkalies by the access of water and atmospheric air to the interior of the earth.

After alluding to the hypothesis of central heat, and pointing out in what respects it fails to account for the phænomena presented by volcanoes, Dr. Daubeny particularised two new facts which lend countenance to the chemical theory. The first of these is the chemical composition of volcanic products, which, according to recent researches, is such as to lead to the inference that they are derived from granitic materials, by the super-addition of those alkaline and earthy ingredients, which would arise from the supposed oxidation of the inflammable bases assumed to exist in the interior of the earth.

The other new fact was the emission of flames from the orifices of Vesuvius and other volcanoes, attributable apparently to the combustion of hydrogen in r combinations, this disengagement of hydrogen being an immediate con the supposed process.

Notices of Experiments in Thermo-Electricity. *By* J. READE, *M.D.*

Some experiments were shown by which a brass bar covered with paper, placed in the focus of a reflecting sheet of copper bent into a semicircular form, and at a short distance from a spirit-lamp, was made to revolve. This Dr. Reade thought to be due to the influence of thermo-electricity.

On the Electrization of Needles in different Media. *By* Prof. C. MATTEUCCI.

Professor Matteucci has found that needles electrized in air, in oil, or in water, were differently affected by the current, the magnetism varying with the nature of the medium in which the needles were placed. The materials employed were the oil of turpentine, olive oil, alcohol and water, and also plates of mica. The discharge of a Leyden jar was then passed near the needles suspended in these fluids, and the amount of magnetization ascertained.

On Crystallography and a new Goniometer. *By* H. B. LEESON, *M.D.*

This new system of crystallography was, during the last session of the Chemical Society, brought under the notice of that body, and illustrated by models and instruments. Dr. Leeson's goniometer consists in adapting to a microscope a polarizing prism; the crystal observed through this polarizing eye-piece of course presents two faces instead of one, but by turning the eye-piece until these two angles are made to correspond, the true angle of inclination from the axial line is obtained, and its value is read off from a graduated circle within which the polarizing arrangement moves.

On the Influence which finely-divided Platina exerts on the Electrodes of a Voltameter. *By the* Rev. T. R. ROBINSON, *D.D.*

Having occasion some years ago to construct a small voltaic battery on Daniell's principle, and wishing to make it as powerful as was consistent with a limited size, I was led to determine its constants by Ohm's theory. Using the voltameter, and grouping observations by the means used in astronomy, I succeeded in this; and when Mr. Wheatstone's paper on the 'Rheostat' appeared, wished to confirm by that instrument my results. The facility of its application led me to other examinations, one of which I have ventured to lay before the Section, as it seems to me important in its bearing on a matter lately brought before the scientific world by Grove and Faraday, namely the intimate connexion of all or nearly all the molecular forces. The galvanometer used by me, being intended to measure powerful currents, consisted of a simple needle suspended in the centre of a massive rectangle of copper. I was in hopes that this simplicity of construction might give some simple relation between the deflection and force, but it was not so; the denominator of Ohm's expression of the force of the current is

$$R + = r\sqrt{\cos\theta}\left\{\frac{A}{\tan g\,\theta} - B\cos^2\theta\right\},$$

as given by careful interpolation; but I have not tried whether this can be deduced from theory. The needle's magnetism was constantly examined and kept at saturation. The rheostat was of Mr. Wheatstone's second kind slightly modified, its wire copper $\frac{1}{18}$th of an inch, and 100 turns of it are 70 feet. The value of E, the electromotive force of Ohm, or rather the *intensity* of the sum or difference of the chemical affinities exerted in the cells is, as in Wheatstone's memoir, expressed by the number of turns of the rheostat required to bring the needle from 45° to 40°. The determinations of it are very consistent, *provided that the magnetism of the needle is constant* and all the apparatus in given positions*.

* The author adds the value of E in the following cases:—

Copper, zinc, dilute sulphuric acid	E = 31·0
Platina, zinc, dilute sulphuric acid	E = 43·0
Daniell's cell	E = 57·0
Ditto, with mur. acid and ammonio-chloride of copper	E = 53·9
Zinc in dilute mur. acid, copper and a mixture of sulph. of copper and nitr. of ammon.	E = 68·0
Grove's cell	E = 13·2

These values neither change with the concentration of the fluids nor with the temperatures.

When one of these cells is connected with a voltameter, no decomposition takes place that is sensible, though a feeble current passes. With two a slight extrication of gas takes place at first and ceases, though it may be made continuous by reversing the direction of the current. Three act steadily: the inactivity of the others is owing to what has been called polarization of the electrodes, but which I would rather name electrolytic resistance. It may be measured as E in turns of the rheostat, and was, with the particular charges which I then used, 2·5 E. Obviously, therefore, two cells could not decompose it, for in that case by Ohm's theory the energy of the current

$$F = \frac{2E - 2{\cdot}5E}{2R + r + y}$$

(y being the resistance of the voltameter) is negative.

This antagonist force is, I believe, referred to the accumulation of nascent hydrogen and its peroxide on the electrodes; and it seemed likely that the evolution of these substances might be promoted by coating the platina with that metal in a state of fine division. This was performed by filling the voltameter with chloride of platina, immersing in it a positive platina wire, and making the electrodes negative. The case was now altered; one cell decomposed feebly with chlorine compounds as charges, but decidedly with sulphates; two give 1·1 cubic inch of the mixed gases in five minutes. With higher numbers the difference is also decided. The quantities given by

3 cells had been	2·5,	now	5·5
6 „ „	9·9	„	11·8
6 double „	18·5	„	25·3

My first impression was that the electrolytic resistance must have been lessened, for the fact of decomposition implies that n E is greater than e in the formula; but on examining it I found that $e = E \times 2{\cdot}49$. Therefore I infer that the force which thus assists the battery in subverting the affinity of oxygen for hydrogen *is of such a nature that the galvanometer does not take cognizance of it*, and therefore is not electric. What then is its nature? The only explanation which occurs to me is, that the energetic capillary attraction which appears to exist at the surface of this platina coating may be, like heat or electricity, convertible into chemical attraction, or that the film of water in contact with it being decomposed, the heat evolved by its condensing a new one (for the intensity of this capillary force is very great) may, as in Grove's recent discovery, aid the separation of the gases. I may add that this peculiar action is more energetic at the positive electrode than the other. I removed the coating from one of the plates by filling the voltameter with muriatic acid, and making it positive. The surface retained however some of it which could not be removed. When this was the negative electrode, more gas was evolved than when it was positive. With 2 cells the quantities are 2·18 and 2·68, with 6 cells 8·60 and 9·12. It may be added, that in all these cases the resistance of the voltameter itself appears to have been the same, the different measures varying from 38 to 35.

On the Electricity of Tension in the Voltaic Battery.

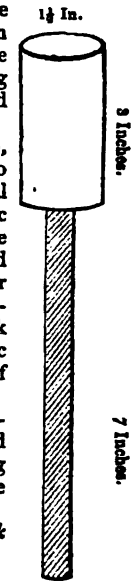
By JOHN P. GASSIOT, *F.R.S.*

The author, referring to a paper presented to the Royal Society in December 1843, remarks that the water battery he then used, which with 3520 pairs gave a continued series of sparks, is at this time nearly as energetic in its action as at first, merely requiring to be refilled with water from time to time as it evaporates.

This was the only arrangement of the voltaic battery by which he was then enabled to exalt the effects of tension so as to obtain the electrical spark before contact of the terminals; although with the assistance of an exceedingly delicate gold-leaf electroscope, he at that time elicited distinct signs of tension in a single cell of Grove's nitric acid battery, and subsequently in one of copper and zinc charged with sulphuric acid. But in all the different series of experiments described in the paper referred to, he invariably found that the higher the chemical affinities of the elements, the greater was the development of the effects of tension. For instance, to produce a certain extent of tension with the gas battery of Grove when charged and hydrogen, ten or twelve pairs of cells were required; with hydro rine, six pairs; with chlorine in a single tube and amalgamated zinc

element, two pairs; and while it took sixteen cells of the water battery to produce a given effect on the electroscope, ten of the same cells when charged with dilute acid produced the same effect in the same instrument.

The static effects of a voltaic battery are very feebly developed, except when the battery is insulated, and the difficulties of insulation in an extended series are at all times great. In the battery excited by acid solutions these difficulties are much increased, in consequence of the conducting power of the liquids; still they are not insurmountable; and as of all the batteries hitherto constructed, the nitric acid battery of Grove is composed of elements of the highest chemical affinity, the author determined on constructing one, in which the effects of tension should be heightened to the extent of exhibiting the spark before the circuit was completed, which he hoped to accomplish without being compelled to extend the series to any extraordinary number, as he had done in the water battery previously described.



For this purpose he had 100 glass cells constructed three inches deep, with stems seven inches long; the zinc of each series was attached to a slip of platinum foil; each cell was carefully charged in the usual manner (but only half-full), with strong nitric and dilute sulphuric acid, and great care was taken that the outside of each cell with the stem was perfectly dry. To the terminals of this battery were attached the copper plates of the micrometer electrometer described in a former paper (Phil. Trans. 1840). On approximating the plates of this instrument to about $\frac{1}{1000}$th of an inch, a series of minute sparks took place, and in a few seconds the usual voltaic arc was produced; this arc could then be elongated to the extent of half an inch, in consequence of the particles of the copper having passed between the plates.

If, in lieu of the copper plates, pieces of charcoal be similarly approximated to $\frac{3}{1000}$ths of an inch, the *arc* is at once produced, instead of the sparks as from the discs; the loose particles of the carbon being more easily detached by the force of tension, and consequently at once producing the *arc*.

The author believes that this is the first instance in which a *true spark* has been obtained from so small a series of the voltaic battery.

On the Decomposition of Water into its constituent Gases by Heat. *By* W. R. Grove, *F.R.S.*

Mr. Grove called attention in the first place to the fact, proved by Cavendish and the French philosophers, that oxygen and hydrogen being exposed to a high temperature the electric spark immediately combined to form water. He stated his belief that the explosion of the mixed gases by the electric spark was due only to the heat of the spark, and not to any specific electrical effect. He then announced his discovery that similar processes to those by which water may be formed are capable of decomposing water. Priestley's method for decomposing gases by passing them through heated tubes was described, and the advantages of using a form of eudiometer devised by Mr. Grove, in which an incandescent platina wire was employed to effect combination and decomposition, were pointed out. By an apparatus of this kind, ammonia, camphor, the protoxide and peroxide of nitrogen were readily decomposed. It was stated that hydrogen gas exposed to the ignited wire always showed the presence of oxygen, and that it is impossible to pass hydrogen gas through water without its taking up so much oxygen as to acquire the power of giving luminosity to phosphorus in the dark.

It was found that if equal volumes of hydrogen and carbonic acid were exposed to the action of the ignited wire, there was a contraction to one volume, leaving a residue of carbonic oxide. If carbonic oxide alone was exposed to the wire over water, the gas expanded in volume, and the carbonic oxide, taking oxygen from the water, was converted into carbonic acid. Here we have two dissimilar results produced by the same cause. By means of hydrogen we take oxygen from carbonic acid, leaving carbonic oxide; and by means of carbonic oxide we take oxygen from water, leaving hydrogen. If steam is formed in the eudiometric tube and acted on by the ignited

wire, on cooling a small bubble of gas is formed, which is found to be mixed oxygen and hydrogen in the proportions in which they form water. This is the result of the first action of the heated wire: in a few seconds a small bubble of gas is formed; but if the action be indefinitely continued, the gas does not increase in quantity. It is however easy to remove the bubble after it is formed, and bring a fresh supply of steam under the influence of the heated wire, and thus to collect a sufficient quantity of gas for an eudiometric examination.

Numerous forms of apparatus were described by which this result can be obtained. It might be objected that, as the wire was ignited by a voltaic battery, the decomposition was not due to the heat of the wire, but to an electric action. This objection would not indeed be maintained by those who were well acquainted with electrical phænomena. With the view, however, of removing all doubt, the use of the battery was entirely done away with, and all the results obtained by the agency of heat alone, in the following manner:—

Into a silver tube a narrow tube of platina is soldered; and this is again connected with a bent tube which admits of the removal of any gas formed. The tubes being filled with distilled water, and the open extremity immersed in a vessel of water, the flame of an oxyhydrogen blowpipe is made to act upon the narrow tube of platina, by which this is brought to a white heat. The water is of course instantly converted into steam, and this steam is decomposed by the agency of the heat alone. By apparent boiling, we thus convert steam into mixed oxygen and hydrogen gases; and this operation may be continued for any length of time by bringing a fresh supply of steam under the influence of the ignited platina. If a fused or intensely-heated globule of platina is plunged into water, bubbles of oxyhydrogen gas immediately ascend from it, which may be collected in an inverted tube.

Prof. Grove went on to show the probable connexion between this phænomenon of decomposition, and the spheroidal state of fluids when projected on capsules of heated platina; this had been referred to a repulsive action of a coating of steam enveloping the spheroid of fluid; but in all probability the spheroidal drop was made to assume a state of tension approaching decomposition by the agency of the heat to which it was exposed. He also entered into several considerations suggested by the above facts as to the relation of heat to chemical affinity, as well as their geological bearings and possible practical applications.

Notice of a Gas Furnace for Organic Analysis. *By* JOHN PERCY, *M.D.*

In this arrangement, gas burnt, mixed with air through wire-gauze, is substituted for charcoal. The advantages are its extreme cleanliness, and the power which the operator possesses of regulating at will the heat, which is not practicable in the ordinary furnace for organic analysis with charcoal.

Extraordinary appearance in the Flame of a common mould candle. *By* E. R. J. KNOWLES.

The writer's attention was suddenly attracted by the light of the candle flitting, as though a moth had flown into the flame, when to his surprise instead of an insect struggling he saw a bright spot revolving with great rapidity in the flame; on examining it, the bright spot was found to be the end of a very fine filament attached to the side of the wick about half-way up the ignited part, and thus held to it, while the extremity with the bright spot of light revolved in a circle like a "Catherine wheel,"—the circle described being about $\frac{1}{4}$th or $\frac{1}{16}$ths of an inch in diameter. It moved with a velocity of about three or four revolutions in a second, and ceased revolving in about three seconds. As stated, when it commenced it was a very small luminous point, and it increased visibly in size as it revolved, becoming eventually a ball or aggregation of carbon, suspended by a single thread like a very fine hair.

Experiments on the Expansion of Salts. *By* Messrs. JOULE *and* PLAYFAIR.

[This paper will be published elsewhere in extenso.]

GEOLOGY AND PHYSICAL GEOGRAPHY.

On the Origin of the Coal of Silesia. By Professor GÖPPERT *of Breslau. Communicated by* Sir R. I. MURCHISON, *G.C.St.S., F.R.S.*

THE Society of Sciences of Holland at Haarlem, proposed in the year 1844, the following prize questions:—

1st. To point out by accurate investigation of the different coal-measures, whether the beds of coal derived their origin solely from the vegetables which once lived upon their present locality, or whether they originated from plants which had been floated thither from other places.

2nd. To inquire whether different coal layers have had a different origin.

At the session of that Society of the 23rd of May, 1846, a paper sent in by me was honoured with both prizes: the suggester of the questions, Professor Von Breda, received a silver medal.

Regretting very much that I am unable to attend the present meeting of the British Association, I beg to submit to the Society's indulgent criticism some extracts from the before-mentioned paper, the materials for which were derived from the coal formations of Silesia. I am now about to extend this inquiry, at the request of the Prussian authorities, to the other coal strata situated in the Rhenish provinces of Westphalia.

Geologists had rarely found in former years any well-preserved plants in the coal itself, and had inferred its composition from the plants that lie in the shale, &c. associated with the coal: my observations in Upper and Lower Silesia prove the correctness of this inference, as I have met with extended coal layers in which the plants (*Sigillaria, Stigmaria, Calamites, Lepidodendra, Nöggerathia*) are still so well preserved that we can distinguish with the naked eye the individual species. These stems, or more properly their barks, lie pressed flat one upon the other, commonly without the inner parenchyma (yet sometimes the latter is preserved and converted into coal), in such a manner that we are able still to recognise, under the microscope, the cells of the parenchyma. Besides this, the so-called mineral charcoal, or fibrous anthracite, does not occur here in single little fragments as it is found elsewhere in the coal, but in broad compressed stems a foot long, which offer the structure of the Araucariæ of our present period (*Araucarites carbonarius*, mihi).

According to the predominance of one or the other genus of plants, I distinguish at many places in Upper Silesia, coal of Sigillaria, Araucarian coal, and Lepidodendron coal, of which the last is far the rarest.

In consequence of these observations I can now give a very simple explanation of the way in which coal has been formed. The Sigillariæ (Stigmaria), Lepidodendreæ, Calamiteæ, containing a softer parenchyme, soon began to be decomposed and disaggregated; but when this process of decomposition was terminated, by early depositions covering the vegetable mass, and the formation of coal was rendered possible, the Araucariæ, which were much harder, and therefore not equally advanced in decomposition, were introduced into the mass in longer fragments, in which the ligneous structure, viz. the parenchymatous wood, cells and medullary rays, are still clearly discernible even under a simple lens. By a more detailed research into the situations which are occupied by all the species of plants detected in the coal itself (which species amount to eighty in number), compared with those plants which occur in the slate-clays and sandstones of the Silesian coal-pits (which produce about four millions of tons a-year), certain positive relations, or modes of distribution, became apparent, such as could not be overlooked. I observed a separation into groups, or the consociated occurrence of certain species; the failing of one species and the substitution of another of the same genus in one and the same coal stratum; and also a different condition of the vegetables in the strata superimposed one on another.

Besides this, the mode of preservation of the fossil plants (ferns with flexible but browned leaflets, &c.), the uniform continuity of many strata with the same thickness over a space of many German miles, the multitude of upright stems, of which as many as 200 have already been observed, with other conditions not noticed here, are proofs of tranquil deposition over the present localities.

On the other hand, calculation shows, that to form such thick strata of coal as occur in our country (to the thickness of from thirty to sixty feet), the plants which could grow upon the same area, even in their most luxuriant condition, would never have sufficed. I therefore cannot but suppose that a large part of our layers of coal have been formed after the manner of our peat moors, during a long course of time; and certainly in the humid way, as I have formerly attempted to show, and as I have more recently exemplified satisfactorily by experiments. If, for instance, we keep vegetables in boiling water for a long time (for three months to a year), they are converted into brown coal (lignite), and they acquire at last a totally black coal-like condition, if we add a small quantity of sulphate of iron, in the proportion of half a drachm to six ounces of plants; no one will doubt that this salt, which occurs so commonly in coal, has largely cooperated in the formation of the mineral.

I may state that many sphærosiderites of the coal have been produced just as our marsh iron ores (Limonite, Rasenerz) now are.

On Sea Water, and the Effects of Variation in its Currents.
By Prof. FORCHHAMMER *of Copenhagen.*

The author, referring to a chemical examination of sea water in different latitudes and currents, tried to show the influence which a change in oceanic currents might have had upon the climate of the North of Europe. The inquiries of Prof. Steenstrup and Lovén respecting the changes in the forest-trees and marine animals indicated a slow increase of the mean temperature of Northern Europe. To account for this, Dr. Forchhammer supposed the British Channel to have been closed, and a polar current to have passed over the lower parts of Northern Russia into the Bothnian Gulf, and thence into the German Ocean. The separation of England from France was supposed to have taken place in recent times; and without quoting the zoological evidence collected by British naturalists, he would refer to physical features,—such as the various changes which the Rhine and the Scheldt suffer at their mouths, and which even the smallest rivulet on the western shore of the Cimbrian Peninsula undergoes. These rivers turn their mouths towards that side from which the tide comes,—one having, in historical times, changed its mouth more than thirty miles to the south. The mouth of the Rhine has been known for about 2000 years; and since the time of the Romans, when it flowed straight towards the north, where at present the Zuyder Zee is, it has been seen constantly turning towards the west. From this change, he inferred a change in the direction of the tide, which he supposes to have arrived formerly at the coast of Holland from the north, instead of from the west, as at present. The marshes on the southern and eastern sides of the German Ocean become broader in proportion as they approach the mouth of the present channel; a circumstance the very reverse of what might have been expected under present circumstances, since the clay is never deposited when there is any considerable motion in the water. On the contrary, if the Channel were shut up, then the present locality of the marshes would be that best adapted for their formation: from which he infers that the principal marshes were formed before the opening of the Channel. The earliest accounts of the Channel date from the fourth century B.C., and at the time of Alexander the Great we find that news of a very great inundation in the northern countries (the Cimbrian flood) had reached Greece; and a tradition still existing in Jutland connects such a flood with the opening of the Channel. Along all the western part of the Cimbrian Peninsula occurs a bed of pebbles, and in some places occur rolled pieces of the clay of the marshes, which must be ascribed to an inundation washing away the lighter materials. This inundation the author regards as that of which both history and tradition speak; and he thinks it was occasioned by the first opening of the Channel. These changes were in close connexion with a depression of the greater part of Northern and Western Europe; which is indicated along the coasts of Denmark and England by submerged forests and peat-mosses. On the shore of the dukedom of Sleswig a *tumulus* has been found in a submerged forest; it contained knives of flint, and shows that the subsidence took place after the country was inhabited. The continuous elevation of the North of Europe would lead to this result,—that the White Sea would flow over the lower parts of Russia

and Finland, bringing cold water and masses of ice into the German Ocean, which being at that epoch a bay receiving waters also which had flowed round the northern coast of Scotland, must have been materially influenced in its climate, so as to have been colder than it is now.

On the Fishes of the London Clay. *By* M. Agassiz.

The Professor stated that since his last report the number of species known from the Paris basin increased; whilst few new forms had been obtained in the London clay. He had however been interested in the examination of specimens of the teeth of the saw-fish (*Pristis*); and had noticed some curious changes which they underwent during the growth of the animal. The young teeth were covered with enamel, and had a notch in their posterior margin; whilst in old tusks the bony material alone existed and the margin was entire. On these grounds he considered the three species of Pristis described by Shaw (*P. semi-sagittatus, microdon* and *cuspidatus*) as constituting in reality only one. Widely as these teeth differed in appearance from the flat, pavement-like teeth of the Sting-rays (*Myliobatis*), their microscopic structure was identical; and Prof. Müller of Berlin had lately shown that the Pristis was not a shark, but belonged to the family of Rays. The Professor then pointed out a peculiarity in the construction of the ventral fins of the Mediterranean Goby, a fish which fixes itself to the bottom by its fins; that act also like springs in enabling the fish to rise from the bottom. He expected soon to be able not only to discriminate every individual bone of any importance in the skeleton of a fish, but also to distinguish the separate fin rays. M. Agassiz then made some general remarks on the geographical distribution of recent fishes. There were many families—of which the flying-fish (*Exocœtus*) was an example—which were found equally in the Indian, Pacific, and Atlantic Oceans. Others, like the Sharks and Rays, were found in every sea from the Arctic circle to the tropics, but the species differed on each coast; whilst some families were confined to the Indian seas, and co-extensive only with the great land animals of that region. The Goniodontes were peculiar to the freshwaters of South America; but these were connected with the Ganoides of North America; and these again closely allied to the Sturgeon, whose affinities have hitherto been little understood. We have here, confined to the New World, all the representatives of an order widely dispersed over the ancient strata. Looking at the distribution of a particular species, like the Silurus, confined to the Danube, Rhine, and a few other freshwaters of Europe, it might be asked by what means it had wandered from one locality to another; to which he would reply that these freshwater fish must have been created in the very streams in which they now live, and in the same proportion as now. They leave the egg in so short a time, that it was quite impossible they should be transported by birds or otherwise. The fishes in the Paris basin appeared to have lived on a coral reef or rocky bottom, whilst those of the London clay were such as in existing seas are found in shallow seas and muddy waters.

On the Artesian Well on the Southampton Common. *By* J. R. Keele, *M.R.C.I.*

It will be seen on reference to the map that Southampton is situated about the middle of a tertiary basin, and in its geological position is not very different from London or Paris. The supply of water hitherto obtained has chiefly been from private wells: almost every house in the town of any pretension as to size or value has one, varying in depth from 10 to 25 feet. It is not known that any well in the town exceeds that depth, since beyond that point, in most parts of the town, we enter the bed of London clay, which lies under the whole district. There is also a fluctuating supply obtained from the Common, about a mile-and-a-half or two miles from the town. The extent of the Common is about 360 acres, and its elevation varies from 100 to 200 feet above the sea-level of the town; the quantity of water got from this quarter has been gained by intersecting the Common in various directions by drains of varying depth from 10 to 20 feet: the water thus collected flows into three reservoirs, from whence it is conveyed into the town by iron pipes. This supply is variable according to the season; in the winter

there is abundance; and in the spring it affords 19,000 or 20,000 cubic feet per diem: in the summer it has fallen as low as 3600, as in September last. Under these circumstances it became necessary to seek for a larger supply. The town is situated on a tongue of land with the rivers Itchen and Test on each side discharging their waters into the estuary called the Southampton Water. The inhabitants would gladly have availed themselves of a supply from the waters of the Itchen, but the late owner of that part of the river which would have been most suitable for this purpose would not grant the supply but upon terms that were unsatisfactory to the rate-payers. This mode of supply was therefore abandoned; and the greater distance of the River Test being an objection on account of the expense it would have entailed upon them, it was also given up; the commissioners were thus thrown back upon their own resources, and determined to ascertain the practicability of forming an Artesian Well. For this purpose an experimental boring was made on the Common, as a preliminary step, in Nov. 1835, and was continued till the chalk formation was reached, in January 1836, at the depth of 480 feet.

In this experiment the diluvial gravel and sand, and upper tertiary strata, overlying the London clay were found to be about 80 feet in thickness, the bed of London clay about 300 feet, and the plastic clay, resting on the chalk, another 100 feet; the boring was continued 50 feet further, when it having been reported that an ample supply of water was to be found at that depth, an act of parliament was soon after obtained for providing the means necessary; and a plan having been fixed on, the undertaking commenced by sinking an iron shield made in segments, which, bolted together, formed as a whole a cylinder of 13 feet in diameter; this shield the contractor purposed sinking to the depth of 160 feet, and from that point to bore to the depth of 400 feet, commencing with a hole of 30 inches, diminishing gradually, and ending with one of 20 inches in the chalk formation.

The work began in July 1838. Two steam-engines were provided, each of twenty-horses power. The estimate and contract for the performance of the work was 10,180*l*., for which the contractor undertook to supply from the well 40,000 cubic feet of water per diem, and provided four gentlemen as securities for the due performance of the work. A spot of land, near where the experimental boring had been made, was chosen for the purpose, being about 150 feet above the sea-level of the town.

Soon after the commencment of the work a failure took place: in sinking the iron shield, or cylinder, more difficulty was found than had been anticipated. Upon arriving at the depth of 60 feet it began to show alarming signs of weakness and unfitness for supporting the enormous pressure it had to sustain; it had, besides this, taken an oblique, instead of a vertical direction. The contractor was therefore obliged to suspend his proceedings, and have recourse to other means of sustaining the pressure on the cylinder by additional supports framed within it of timber, and in this way preventing any sudden disruption by which the lives of the men employed on the work might have been sacrificed. At this period the undertaking was given up by the contractor, and the four gentlemen who had been accepted as his securities were compelled to go on with the work. They began by repairing the shield, which had been broken in several places, and having rendered it secure, with great labour and expense, a cylinder of smaller dimensions was framed within the old one, of 9 feet 10 inches in diameter, formed by eight tiers of plates, or sections, each 5 feet in depth, and $\frac{1}{4}$ths of an inch in thickness, of cast iron. The old cylinder being first supported by strong chains, the new one was forced down through the sand by heavy pressure till it was lowered to a sufficient depth, and rendered secure by resting on a dome of brickwork, built under it by underpinning, in sections of 3 feet at a time, gradually increasing in diameter till the original diameter of the shaft was again attained. The shaft was then carried down in solid 14 inch brickwork, set in Roman cement. At the depth of 85 feet they passed through a solid mass of very hard stone full of black water-worn pebbles, and loaded with shells of various kinds, characteristic of the London clay. On the 1st of February 1840, the shaft was complete to the depth of 100 feet; the quantity of water which now flowed into the well was kept under by two pu and estimated at about 4000 cubic feet per diem. April 2, 160 feet of the shaf complete. A question now arose as to future proceedings: the original pla

to form a shaft of 13 feet in diameter to the depth of 160 feet, and then to commence boring, beginning with a bore hole of 30 inches, and ending with one of 20 inches at the depth of 560 feet. The undertakers now proposed to continue the work by a shaft of 7 feet in diameter, carried the whole way into the chalk, instead of boring as originally intended. The commissioners acceded to this alteration, and agreed to share the additional expense, provided the contractors would have a shaft of larger dimensions than 7 feet. The contractors having agreed to this proposal, it was continued onward with a shaft diminished in diameter from 14 feet to 11 feet 6 inches. At this period of the work the candles could hardly be kept lighted in the well, and they were obliged to have an air-tube constructed of zinc, with a pair of bellows attached, worked by the steam-engine, for the purpose of ventilating the well.

The work was frequently impeded by large masses of stone, full of shells and rounded pebbles, which had to be raised out of the shaft; and it was observed at this time, on looking upwards from the bottom, that the shaft was filled with a dense vapour like fog or steam, and it was thought that if the bellows and air-tube had not been employed it would have been impossible to have proceeded with the work.

Some of the beds of stone occupied a space of 6 feet in depth, particularly one from 174 to 180 feet in the well. The work however still proceeded, and on the 10th of September the shaft was 214 feet. It was then reduced to 10 feet in diameter. By October 31st 270 feet of the shaft was complete, and then reduced to 8 feet 6 inches.

It was the custom of the excavators at this time to bore onwards several feet before they began another section; by this means water was found at the depth of 312 feet in considerable quantity, in a bed of sand, which obliged them to discontinue the shaft in brickwork and employ iron cylinders: by this means the influx of water was got over, and the work advanced slowly till it had attained the depth of 322 feet. The soil having again become more solid, the shaft was again resumed in brickwork of 7 feet in diameter. At this depth the quantity of water raised by the pumps amounted to 30,240 gallons in twenty-four hours. There appears to have been no peculiar difficulty in proceeding with the shaft from this period.

On the 14th of August, 1841, a change of colour was perceived in the soil, and it was found they had arrived at the surface of the plastic clay, being 380 feet from the top of the well. The whole bed of plastic clay was then passed through with no other difficulties than those which took place from accidents to the machinery: very little sand and no water was found in that formation.

The shaft was continued onward in brickwork of 7 feet diameter till the chalk was reached, on the 8th of November. The workmen were then employed in finishing the brick shaft, which was carried down to the solid chalk, and rested 3 feet below its surface. The excavation was then continued onward, of the same diameter, without brickwork, and the chalk kept fair with the inside face of the shaft. On the 4th of December they had attained the depth of 520 feet, the work having been carried on day and night. The quantity of water which now flowed into the well from the chalk was ascertained to be about 3 gallons a minute.

The temperature of the water was now taken at the bottom of the well and found to range between 61° and 62° of Fahrenheit; the temperature of water at the surface was 44°; the atmosphere of the well at 50 feet, was 54°; at 160 feet it was 60°; at 543 feet it was 65°.

On the 22nd of December an accident happened to the machinery, and the work was suspended to the 3rd of January, 1842: the shaft was now 550 feet deep.

On Friday, March 4, it was again measured, and found to be 562½ feet below the surface of the earth. At this period, the pumping having been discontinued one week, the water rose 400 feet in the shaft, which amounted in quantity to 21,578 cubic feet. The well was now of the depth required, but the quantity of water was not sufficient for the full performance of the contract.

The town being in great want of water, public meetings were held, and great complaints of the scarcity were continually heard.

The contractors finding they had been deceived by the report that an abundant supply of water was to be obtained from a depth much less than that to which they had carried the work, thought it best that the shaft should be carried on still further,

as being the best mode of obtaining the quantity of water required. They therefore made a proposal of this kind to the commissioners, which, if adopted, would in all probability have been successful in obtaining the quantity of water required, or have led to the plan of making lateral galleries or drift ways in the chalk, and following up any indications of water which might have been found, as was afterwards suggested by Dr. Buckland. The commissioners, however, would not accede to the proposed continuation of the shaft, and upon their refusal the contractors determined to carry it no further, but commence boring. They therefore purchased the implements necessary, at the cost of 1000*l.*; and the work was carried on from a stage fixed about 40 feet below the surface of the well, from whence the boring-rod was conducted to the bottom of the shaft by means of an iron tube fixed in the centre of the well. By this means the operation of boring was carried on through the column of water, and the enormous expense which they had hitherto sustained of pumping day and night was saved. The commissioners seem not to have been prepared for this expedient—expecting, perhaps, that the inhabitants would continue to receive the overflow of the well while the work was in progress as they had hitherto done, free of expense; finding, however, this was not to be the case, and a scarcity of water being severely felt during every summer, they were obliged to come to terms with the contractors for a supply of water from the well.

In the meantime the operation of boring, which commenced in March 1842, was carried on with the greatest labour and perseverance to March 1844, with a 7½ inch auger, and other tools necessary for breaking up flints, &c. The progress of the work during this long period was at times very slow, from the numerous difficulties and impediments encountered. It would be occupying too much time to relate all the misfortunes they met with from the breaking of their boring-rods and other machinery, which appear to have been quite as many and as difficult to overcome as those encountered by the fortunate and skilful constructors of that unrivalled work at Grenelle, of which the French nation may well be proud. It will be sufficient to say that all have been surmounted by the skill and ingenuity of Mr. Docura and Mr. Joseph Hill, under whose management the boring was conducted, and carried to the depth of 1260 feet. After the commencement and during the continuance of this operation, the quantity of water was found to increase progressively, gradually rising in the shaft to much higher levels; and at the time the boring was suspended in 1844 the water rose to within 40 feet of the surface, where it reached the boring stage*.

Previous to the commencement of the boring in 1842, 600,000 gallons of water per month were raised from the well to supply the inhabitants when the scarcity of water became very pressing. In 1844, after having made considerable progress in the boring, the contractors entered into a further agreement to raise from the shaft 1,200,000 gallons per month. In 1845, during upwards of four months' daily pumping, the delivery of water was at the rate of upwards of 1,500,000 gallons per month. Alterations were then made in the machinery for pumping, which enabled the contractors to raise the water from a much greater depth in the shaft, and the result was, that on a trial of eight successive days, the quantity of water raised exceeded 725,000 gallons, being at a rate of upwards of 2,500,000 gallons per month. When the pumping was stopped in November 1845, it was found that the water rose rapidly to its former level, viz. 40 feet from the surface, at the following rate:—at 120 feet from the surface, the water rose 2 feet per hour; at 130 feet, 2 feet 4 inches; at 140 feet, 2 feet 7 inches; at 150 feet, 2 feet 10 inches.

In measuring the capacity of the shaft at these depths, it will be found that at 120 feet the water flows into the well at the rate of 277 cubic feet per hour; at 130 feet, at the rate of 310 cubic feet per hour; at 140 feet, at the rate of 343 cubic feet per hour; at 150 feet, at the rate of 376 cubic feet per hour; and so on, increasing 33 feet every 10 feet in descending the well.

* Memoranda recorded by Mr. Joseph Hill.—Previous to boring, the water-level in the well was 57 feet from the surface; since the boring the water has risen to 40 feet, being an increase of 17 feet in the water-level of the well. On the 27th of July, 1845, after the pumping was suspended, the water was found to have risen 68 feet in thirty-eight hours. 1846.—On the 28th of August, the pumping having been stopped at the depth of 306 feet, ir the water rose in the well to 225 feet, being 81 feet during that space of time.

The quantity of water which the shaft will contain below the present water level is as follows:—

120 feet at	13 feet 0 inches diameter	15,927 cubic feet.
50 feet at	11 feet 6 inches diameter	5193 cubic feet.
50 feet at	10 feet 0 inches diameter	3927 cubic feet.
50 feet at	8 feet 6 inches diameter	2837 cubic feet.
250 feet at	7 feet 0 inches diameter	9621 cubic feet.
520	Total	37,505

In conclusion, the question we have now to settle is, whether it is better to be content with the well in its present condition, or continue the boring, for the chance of obtaining a larger and less expensive supply from the greensand formation. The example of our neighbours on the other side of the channel certainly affords us much encouragement to proceed with the work; but we have not sufficient confidence in our own opinions to venture on such a step without the advice of those whose scientific knowledge and better judgement we are most anxious to obtain.

On the Applicability of M. Fauvelle's *Mode of Boring Artesian Wells to the Well at Southampton, and to other Wells, and to Sinkings for Coal, Salt and other Mineral Beds. By the* Very Rev. W. Buckland, *D.D., Dean of Westminster, F.R.S.*

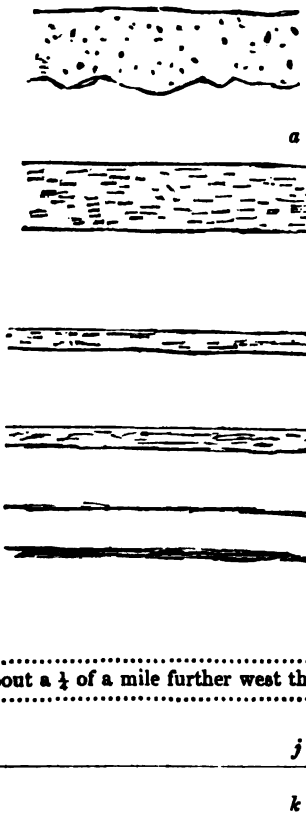
Dr. Buckland recommended that the boring on Southampton Common should be continued by M. Fauvelle's method. He stated that there was probability of obtaining a more abundant supply of water by going deeper into the chalk; but that it would rise no higher in the shaft than the level of the nearest outlet at Otterbourne, where the water of the chalk makes its escape. From the observations of Mr. Clutterbuck, it appeared that the water stands gradually higher in the wells on the line of railroad between Southampton and Basingstoke, at the rate of about a foot higher for every mile.

The water in the greensand beds next below the chalk was derived from rain that falls in districts where these sandy strata form the surface of the country; the nearest of these surfaces being in the axis of the Isle of Wight, and in the Vale of Petersfield, and the Vale of Pusey. From these three districts (unless where cut off by a fault) there was probably a subterraneous passage for water through the interstices of the upper greensand beds, beneath the whole of the Hampshire basin, this water being upheld by subjacent impervious beds of *gault* clay. The height to which this water could rise through a hole bored in the chalk, would depend on the levels at which the springs from the greensand nearest to Southampton find their issue. These levels should be ascertained, especially near Petersfield.

On the occurrence of Cypris in a part of the Tertiary Freshwater Strata of the Isle of Wight. By Joseph Prestwich, *Jun., F.G.S.*

Although a species of this small crustacean abounds in the tertiary lacustrine deposits of Auvergne, and is not uncommon in the upper beds of the Paris basin, whilst lower in its strata M. D'Archiac quotes a new species in the 'Gres de Beauchamp,' and the *Cypris punctata* from the plastic clay or lignite group, yet it is extremely rare in the English tertiary series. In the London basin I believe that no freshwater form of it has been found; one species of the marine form, the *Cytherina*, has been met with at Highgate. In the Hampshire basin, mention is made by Mr. Lyell, in the third volume of the Transactions of the Geological Society, of the rare occurrence of an undescribed, and, I think, a tuberculated species in the freshwater strata at Hordwell Cliff. In the fine sections of Alum Bay, Headon Hill, and White Cliff Bay, in the Isle of Wight, amongst the other abundant organic remains, I never detected any fossil Cyprides. Having lately had an opportunity of making a hasty visit to Hampstead Cliff, about 1¼ mile east of Yarmouth, I there found a species of Cypris in considerable abundance. The cliff being composed chiefly of beds of clay and marl, forms a surface easily acted on by the weather, and presents innumerable slips and prolonged

slopes covered with thick underwood, rendering good clean sections extremely scarce. In fact, at present only two or three small openings, where the succession and order of the strata are clearly exhibited, occur. The best one is near the brow of the cliff at one of its highest points; it presents the following group:



Thickness in feet.		
10		Sandy flint gravel.
6	*a*	Greenish grey marl with a few *Cyrena obovata*.
2	*b*	Dark clay full of *Cyrena obovata*, *Potamides* and *Melania*.
8	*c*	Laminated dark grey and brown clay, with large Septaria and shells in patches. *Corbula* common. Impressions of plants.
½	*d*	Clay full of *Corbula*.
3	*e*	Dark grey clay with *Paludina lenta*, *Unio*, *Corbula*, *Melania* and *Natica*.
½	*f*	Band of *Unios*.
2		A comminuted mass of *Cyrena*, *Melania*, and *Potamides*.
½	*h*	Bed of small *Melania*.
	i	Green and red marls; section imperfect; probable thickness almost 25 feet; few or no fossils.

About a ¼ of a mile further west this last bed is seen to repose on

1	*j*	Laminated brown and grey clay with small *Melania*; minute bones and teeth.
2	*k*	Brown clay, full of *Cypris*, small *Melania*, and seeds of plants.

This appears to repose on red and green marls, with few or no fossils, and at the bottom of the cliff a thin band of ironstone full of *Paludina lenta* crops out.

We thus have in the lower part of this section a deposit containing essentially freshwater Testacea, becoming more mixed as we ascend, with shells frequenting æstuaries. Impressions of plants are not uncommon, and seed vessels (of the same species as those at Tolland's Bay) are found in abundance in stratum *k*.

It is a singular feature in this group, which I believe to form the upper beds of the freshwater formation of the Isle of Wight, that a large proportion of the species occurring in it are new; thus the two characteristic fossils are a species of the *Potamides* and one of *Melania*, neither of which do I find described. The Cypris also is peculiar to this locality. It is distinctly different from the *Cypris faba*, neither is it tuberculated. Some very small vertebræ and bones are far from rare. Professor Sedgwick, as far back as 1818, described in the 'Annals of Philosophy' the peculiar mixed freshwater and æstuary character of the strata in this locality. Since then they have not been much noticed. I hope that they will now be more closely examined, for I have little doubt but that, from the peculiarity of conditions, they will yield an interesting series of organic remains. I have merely time to point them out.

In a note in the last number of the 'Journal of the Geological Society,' I alluded to the discovery by Mr. Pratt of impressions of plants in a stratum which I believed to correspond with No. 17 in the Alum Bay section. This I can now confirm, and testify to their great abundance and beautiful state of preservation, but from their light colour (being nearly that of the clay) they were long overlooked.

With regard to Headon Hill, I regretted to find its cliffs so fallen down and its fine sections comparatively so obscure; still the interpolated marine beds, Nos. 56 to 60, can easily be traced at intervals. The fossils of these beds can now be best procured at the eastern extremity of the hill. At Colwell Bay however the section continues extremely well exposed and full of interest.

On the Arrangement and Nomenclature of some of the Subcretaceous Strata. By W. H. Fitton, *M.D., F.R.S.*

This communication included a summary of the latest inquiries on the strata immediately beneath the chalk in England; with a *table* of the fossils (connected with a paper previously read before the Geological Society of London), from a new collection made by the author in the cliffs near Atherfield, in the Isle of Wight, from the gault down to the Weald clay. The specimens were named by Mr. Morris, and compared with the series in the Geological Society's Museum catalogued by Professor Edward Forbes. This tabulated arrangement exhibits about 150 species, in their true places; so that numerous results can be obtained from it, respecting their relative positions and distribution in the series of strata. 1. The accumulation of species in the lower part of the section is very remarkable; about 130 of the total number originating within 150 feet from the bottom, while not more than twenty other species originate in the remaining portion; the thickness of the entire section being 800 feet. The absolute numbers also of shells diminishes rapidly upwards, and in the strata near the top of the section in this part of the Isle of Wight, even indications of fossils are rare; though near Shanklin, and near Folkstone in Kent, the fossils of the corresponding beds are more numerous and distinct. 2. These and other facts indicate the existence of only one series of fossils, throughout a period of continuous but unequal deposition,—the gault, with its peculiar and characteristic fossils, being immediately above,—a result which perfectly accords with the view taken by Professor Forbes, in a paper published by himself and Captain Ibbetson, in the 'Geological Journal' (vol. i.). 3. The upper and less fossiliferous portion of the section here, is distinguished, if not separated, from the lower beds by the presence of a very remarkable group of ferruginous concretional bands, which occurs in a corresponding place, at Horse-ledge, west of Shanklin Chine; at Parham Park, in Sussex; and at Sandgate, in Kent: including in all those places the same fossils, *Thetis, Gervillia, Trigonia, Rostellaria,* &c. 4. From the general mode of distribution of the species, as above described, and the great variation in the components and proportion of the beds which form the sections of the lower greensand in different places, it may be inferred that subdivisions, founded on the occurrence, or grouping of the species, cannot be expected to be either generally prevalent or very precise. 5. The remarkable deposit of Neufchatel (*Terrain Néocomien*) appears to be the equivalent of the lower part only of the section near Atherfield, the upper divisions being wanting at the former place. In most of the published sections of the subcretaceous groups in France and other places, an upper division or series of strata, like this of the English coast, is likewise found, under the names of *sables verts, sable ferrugineux, jaune,* &c. The Atherfield section, therefore, includes the *Terrain Néocomien*, with the addition of the group last mentioned, which at Blackgang Chine is not less than 250 feet in thickness.

Captain Ibbetson and Prof. Forbes exhibited models and sections of various parts of the Isle of Wight, and pointed out the localities and geological features most interesting to visitors.

Sir R. I. Murchison presented, on the part of Dr. Mantell, a Geological Map of the Isle of Wight, and the preliminary pages of a work devoted to the description of the island.

On certain Deviations of the Plumb-line from its Mean Direction, as observed in the neighbourhood of Shanklin Down, in the Isle of Wight, during the progress of the Ordnance Survey. By W. HOPKINS, *F.R.S.*

The difference of latitude between Greenwich and the station of the Ordnance surveyors at Dunnose, on the *north* side of Shanklin Down, as determined by triangulation, was *greater* by 2·22 seconds than as determined by zenith sector observations. When, however, a new station was chosen on the *south* side of Shanklin Down, the difference of latitude, as determined by triangulation, was *less* by 3·09 seconds than it appeared to be when determined by the zenith sector. These discrepancies would be accounted for, if the mass intervening between the stations at Shanklin Down were sufficient to produce, by its attraction on the plumb-line, the observed deviations. The requisite calculations for proving the adequacy of this cause had not been made; the tendency, however, would necessarily be to produce effects of the same nature as those observed; and the author thought it probable that the intensity of the attraction of the hill would be found sufficient to account for the phænomena.

On Railway Sections made on the Line of the Great Western Railway, between Bristol and Taunton. By W. SANDERS, *F.G.S.*

The general section is made to the scale of 33 inches to the mile, or 1 to 1920; extending over a length of 45 miles. The colours are those of the Ordnance Survey.

In four places the sections are enlarged fourfold, or 40 feet to the inch; and full details are given on the scale of 4 feet to the inch. The colours of the Ordnance Survey are taken as a basis, and others are introduced to describe local facts. The railway passes first through the junction beds of red marl and lias; then for six or seven miles through new red sandstone, interrupted only at one place, where a tunnel, 324 feet in length, pierces the upper beds of the carboniferous limestone; then for about twelve miles chiefly over alluvial tracts, separated by cuttings of new red sandstone beds, also touching the southern margin of the Nailsea coal-field. At twenty-one miles occurs the Uphill cutting, passing through new red sandstone and lias, and then carboniferous limestone, at the base of which is seen some masses of trappean rock. The railway is then carried along an alluvial plain of seventeen miles in length, interrupted only in one place, at three miles north of Bridgewater, by a deep cutting through new red marls and lias at Puriton. From the termination of the alluvial tract to Taunton, the course is over a moderately level country of new red sandstone, and little occurs to attract the attention of the geologist, except the occasional appearance of diluvial gravel, which is seen to contain an increasing proportion of the killas as the observer approaches Taunton. There are four enlarged drawings.

It is desirable to notice first, that called the Ashton cutting, where the carboniferous beds are displayed in three places. Over the two smaller masses and on the sides of the larger one are seen the usual boulder conglomerate, consisting of large and small fragments of limestone, partially water-worn, cemented by the ordinary red clay. As the superincumbent strata are carried over the two small masses of limestone, and apparently tend to ascend over the rock at the tunnel, it might be supposed that a local elevation had taken place subsequent to the deposit of the new red sandstones. This may have been the case, but the inclination and curving of the beds may have been original; and I incline to this opinion, since, on the presumption of the limestone having been elevated by violent force arising from igneous action, the conglomerate adjoining the limestone would have been pierced and thrust aside, and greater displacement manifested in the marly clays above.

At the Uphill section the evidence differs: here not only are violent dislocations of the red marls and lias produced, so that the lias beds dip at an angle of 70° or more towards the plane of intersection between the lias and the limestone, which plane itself dips in the same direction; but, in addition, the igneous rock appears in full force; and it clearly bears relation not only to the fault, which brings into juxtaposition the limestone and lias, but to an extensive fault in the limestone itself, by which the whole series of beds on one side differs from that on the other.

On the nature of the trap rock and its metamorphic influence on the limes-

the Rev. D. Williams of Bleadon has sent to the Geological Society papers which have been published in their volume of Proceedings; my own view differs very materially from that of Mr. Williams, and I prefer making no further remark on this matter.

I pass on to the new red sandstone. The first section at Pylle-hill traverses the upper part of the red and pale-blue marls. Here the stratum containing the strontian nodules is displayed, and at this spot were found those beautiful crystallizations of strontian, specimens of which may be seen in many mineralogical collections of this country; the crystals being not only remarkably large, but presenting modifications highly interesting to the crystallographer. The Ashton cutting does not touch the red marls, but is limited entirely to the sandstones beneath the marls. On the drawing the layers of stone are marked with dark-red lines, and the detailed description also inserted. The Uphill and Puriton sections show the red and blue marls; and the only remark at present necessary is, that in the Uphill section the strontian and gypsum of other localities are here replaced by nodular cavernous concretions of minute crystals of carbonate of lime.

I now proceed to the consideration of the lias strata: the lower divisions of the lias are seen in three of the sections. The general features of the Pylle-hill and Uphill sections are the same, and the organic remains usually accompanying these beds are found in each. In the Puriton section the corresponding beds are expanded to a much greater thickness than any other with which I am acquainted in the Bristol district. Very few fossils have been obtained on this spot, and the shaly clays intervening between the limestones are so thickened and are so uniform in composition, that the symmetrical structure of the mass causes the face of the cliff to present a series of very smooth divisional planes in two sets, the direction and dip of which are set forth in the details of the section.

I am unwilling to close these remarks without adverting to the classification which M. Agassiz has adopted for the position of the bone-bed of the Aust cliff. By this naturalist, and by other eminent persons also, the Aust bone-bed is classed as a part of the Triassic series, in consequence of the presence in each of the same species of fishes. The facts I wish to state, bearing on this question, are these: the strata of the lias, which are beneath the white lias limestones, of which lower division the Cotham marble forms the upper bed and the bone-bed the lowest, were deemed by Mr. Conybeare sufficiently characteristic as a group of sedimentary deposits, irrespective of its organic contents, to merit a distinguishing name—the lower marls.

This group then contains throughout its whole extent the same, or apparently the same, fish-scales and fish-teeth as are preserved in the bone-bed. Besides the occasional occurrence of such relics in the clays of this group, there are in the Aust cliff three calcareous layers above the bone-bed containing these remains abundantly. In the Pylle-hill and Uphill strata occur the same number of such beds, and the latter section affords but a poor equivalent of the bone-bed. In the Puriton sections there is one, and probably more than one calcareous stratum yielding fish-scales, and the bone-bed is very faintly exhibited. Further I am not aware of these remains above the Cotham marble. There is also a Pecten peculiar to this group, but I cannot state the species, as I believe it to be undescribed. Should any one be disposed to connect the whole group of lower marls with the bone-bed and remove them from the lias, there would arise this objection: the Cotham bed, the highest limit of the lower marls, contains not only the fish-scales, but insects of the same species as are found in the white limestones above, and the same likewise as were found by Mr. Edmund Higgins of Clifton at Aust, at a distance of only ten feet above the bone-bed. Moreover, Mr. Higgins has discovered the Cypris with plants in the white limestones in association with the elytra of insects, and a few weeks ago I discovered in the Pylle-hill cutting, in the midst of the lower marls, the Cypris with the plant *Naiadites lanceolata*. I am therefore inclined to think that the whole group of strata, including the Cotham marble above and the bone-bed at the base, should be treated as a subordinate member of the lias formation, and that no portion of the same should be considered as an equivalent of any part of the Triassic group. The decision of the question must however depend upon a much closer examination of the organic contents than I have been able to devote to them.

On three Sections of the Oolitic Formations on the Great Western Railway, at the West End of Sapperton Tunnel. By Captain IBBETSON, *F.G.S.*

The author presented a short communication to accompany three detailed sections, surveyed by the author for the Geological Survey of Great Britain, for the purpose of showing the continuation of strata described by Mr. Lonsdale, and in the 'Geology of Cheltenham,' by Sir R. I. Murchison, by Mr. Buckman and Mr. Strickland.

The section at the mouth of the tunnel shows the great oolite, fuller's earth, and the upper rag of the inferior oolite, which contain three remarkable strata; viz. a zone two feet thick, consisting of a mass of *Trigonia costata*, and another species of *Trigonia angulata*, &c.; the second, composed of *Gryphæa cymbium*, &c.; and the third an immense quantity of Terebratula, particularly *T. fimbria*. The beds were noticed by Mr. Lonsdale as being found at Witcombe Hill near Bath, and by Mr. Buckman as occurring in the Lineover section. The only lithological difference between the Sapperton sections and the Lineover section is, that the thin bed of fossiliferous clay at Lineover is at Sapperton a very hard grit, crystalline, and a mass of comminuted fossils. The second section contains the upper rag of the inferior oolite, with the three zones above-mentioned; and the third the upper and lower rags of the inferior oolite, separated by a mass of soft freestone split obliquely, very crystalline, and full of comminuted fossils.

On the Age of the Silurian Limestone of Hay Head, near Barr Beacon, in Staffordshire. By JAMES BUCKMAN, *F.G.S.*

The limestone rocks and shale of Hay Head, celebrated as the original locality from whence was obtained the Barr Trilobite (*Bumastus barriensis*), were referred by Sir R. I. Murchison to the Wenlock series of the upper Silurian system. This opinion having been doubted by Burmeister, who places the Barr Trilobite in the lower Silurian division, Mr. Buckman commenced an examination of all the fossils associated with that species at Hay Head. Of the fifty-six species there obtained, fifty-three belong exclusively to the upper Silurian beds, and have also been found in the Wenlock series of Dudley; whilst *only one*, and that a doubtful species, can be referred to a lower bed. The author hence concludes that Sir R. I. Murchison's sections and notes upon this locality are correct; though he considers it probable that a seam of the coal measures occupies a small tract in the valley between Hay Head and the town of Walsall.

Notice of the Discovery of a new Species of Hypanthocrinite in the Upper Silurian Strata. By JAMES BUCKMAN, *F.G.S.*

The genus Hypanthocrinites of Phillips, of which a single species was known to Sir R. I. Murchison, and is figured in the 'Silurian System' under the name of *Hypanthocrinites decorus*, pl. 17, f. 3, is in itself so remarkable, and presents such peculiarities of structure, that any addition to the list of species cannot be considered otherwise than interesting to the fossil zoologist. Through the kindness of Augustus Lewis, Esq. of Wolverhampton, to whom the discovery is due, Mr. Buckman is permitted to lay a beautiful and unique specimen of a new species before the Geological Section of the Association.

From the specimen itself, and from an enlarged drawing which he has made of it, as well as of the previously known species, there is no difficulty in making out the following distinctive characters: *Hypanthocrinites granulatus*, Lewis's MSS. *Head* large, obtusely conical, apex surmounted by a small proboscis. *Inter-digital* ribs square on their outer margins, which are dotted by minute granulations; these are terminated by smooth plates, concave on their outer surfaces. *Fingers* like those of the *H. decorus*, but larger. *Body and columns* absent.

This species therefore differs from the *H. decorus* in being of a much larger size, with a more obtuse apex; in its small proboscis, which is only about one-fourth the size of that of the *smaller* species; in its ribs being flat externally instead of convex; and in these again being granulated, whilst in the *H. decorus* they are smooth: the ribs in the last-mentioned species are surmounted by large *tubercular* plates, whilst these are *narrow* and *concave* in the new specimen.

The specimen described was discovered in the shale between Hay Head and Walsall, which is now being cut through for a canal, and is the only example that has yet been obtained of this very fine and remarkable fossil.

Mr. James Yates exhibited a series of specimens of *Zamia Gigas* (Lindley's Fossil Flora, iii. 165), from Runswick, near Whitby, and offered some observations on the apparent structure and connection of the several parts of the plant.

On the Mushet Band, commonly called the Black-band Ironstone of the Coal-field of Scotland. By Robert Bald.

This band of ironstone was discovered, about forty years ago, by Mr. David Mushet, of the Calder Iron-works, near Glasgow. It had been frequently passed through, but was thrown away as rubbish till Mr. Mushet ascertained its value, when extensive mines were opened for working it. Two bands of this ironstone are found in the great coal-fields of Lanark,—one fourteen inches thick; the other, which is seventy-three fathoms lower, is sixteen inches thick. The ironstone of the Mushet band is much more easily reducible than the ordinary clay ironstone, and requires less fuel. In Scotland it appears to be co-extensive with the coal formation. In South Wales also it is found; but there is little of it in England or Ireland. Fifty years ago there were only five iron-works in Scotland, comprising about fifteen blast furnaces, which, together, produced 540 tons of iron per week. There are now 100 blast furnaces in action, which produce 12,000 tons per week, or 624,000 tons in the year, the value of which, at £3 per ton, is £1,872,000. This great increase Mr. Bald attributed to the discovery of the Mushet ironstone, and to the introduction of the hot-blast. He also mentioned that Mr. Mushet, who is now in his seventieth year, has published a volume on the manufacture of iron, containing an analysis of every ironstone and ore he could obtain; and he trusted his labours would, at least, be recognized in scientific societies, although the pecuniary advantage arising from his discoveries had fallen into other hands.

On the Extent of the Northwich Salt-field. By G. Wareing Ormerod, *M.A.*, *F.G.S.*

The prevailing direction of the faults in the coal-field of South Lancashire approaches to the magnetic north and south. Of those faults some extend to the new red sandstone of Cheshire, under which they probably pass; others can be traced across the new red sandstone. Of the last, one passes in a magnetic north and south direction through the coal-field of Lancashire, by the west of Wrightington and Haydock-lodge, and Warrington. Here it enters on the new red sandstone of Cheshire, and passes by the west of Hill Cliff and Northwich, forming the south-western boundary of the Northwich salt-field. At Barnton and Hartford to the *west* of this line of fault rock-salt has not been discovered, though sunk for to the depths of 300 and 400 feet respectively. At Northwich, to the *east* of the line, rock-salt occurs, as shown in the following section.

	Feet.	Inches.		Feet.
To upper salt, about	87	0		
Upper salt, from	80	0	to	90
Hard clay	30	0		
Second salt, from	96	0	to +	117
Stone	5	8		
Salt and clay	6	7		
Pale red salt	3	4		
Stone with thin laminæ of salt	13	9		
Pale red salt	6	0		
Stone with veins of salt	7	6		
Lowest bed of salt reached	11	6		
Stone	77	0		
Stone with detached crystals of salt	9	0		
Stone with salt between laminæ	11	0		

This fault is continued between Middlewich and Winsford. At Middlewich the

strata have been penetrated to 214 feet below sea-level without finding rock-salt. The brine rises there to a height of about 130 feet above sea-level; whilst at Winsford rock-salt beds, similar (as far as worked) to those at Northwich, occur at a depth to the upper bed of from 90 to 120 feet below sea-level. The brine rises there to a height of about twenty-five feet above sea-level. The line thence passes into Staffordshire, near Whitmore.

A fault ranging from south-west to north-east, passes by the north-west of the Peckforton hills across Delamere Forest, by the north-west of Northwich, dividing that salt from the easterly ends of the Waterstone, or lower beds of the keuper, and thence to the east of Timperley. The north-east boundary of the Northwich salt was not determined. The south-east is formed by a line parallel to the north-west side, about 1300 yards distant therefrom.

Within this area frequent subsidences of the land take place. From this cause the locks on and the banks of the Weever have been here raised. The land where a factory stood, near Northwich-bridge, has sunk so as to form a wharf. A few years since, the subsidence near the junction of Whitton-brook and the Weever was at the rate of three inches per week: at this point a lake is now rapidly forming. The salt pans at the works by the Weever have been frequently raised, and many are now abandoned. The course of Whitton-brook, which in 1811 was made six feet deep, now varies in depth from ten to thirty feet. About two miles to the north of Northwich, near the north-western boundary fault, some fields are sinking. In this area the brine stands at the same level, and varies simultaneously in all the pits. That the rock-salt of Northwich does not extend beyond the above limits, is further shown by the fact, that the neighbouring ground beyond the above boundary lines does not sink, and the brine where found beyond the said boundary is reached and stands at various levels—all differing from that at Northwich.

Minute descriptions of the salt, and the methods of working the same being given in various well-known works, the same were not here noticed.

Notice of the Coal of India, being an Analysis of a Report communicated to the Indian Government on this subject. *By* Prof. ANSTED, *M.A., F.R.S.* &c.

The coal districts of India may be considered as five in number,—three in Northern India and one in Cutch, whilst the fifth includes the province of Arracan and the coast of the Birman empire near Tenasserim. Of these the Cutch coal is certainly not of the carboniferous epoch, and it appears to be of little importance at present and unpromising.

The whole district, extending from the neighbourhood of Hoosungabad on the Nerbudda river (lat. 23° N. long. 78° E.), on the left or south bank of the river, and extending in a north-easterly direction for a distance of about 400 miles to Palamow, thence eastward, for 250 miles, to Burdwan, near Calcutta, and running northward, for 150 miles, to Rajmahal, exhibits, it would appear, at intervals by no means distant, a continually repeated outcrop of rocks, consisting of sandstones and shales, with occasional limestone. Throughout this wide tract a number of beds of coal have been recognised, of variable thickness and value, but all appearing to exhibit evidence of the existence there of a great coal-district.

On the flanks of the Garrow Mountains, near the Burhampooter, and on both banks of that vast river, we find another, perhaps a continued outcrop of similar beds, also containing coal, and reaching in a north-easterly direction for nearly 400 miles. The intermediate plains, whose breadth between Rajmahal and Jumalpore is about 100 miles, are chiefly alluvial, and thus it is possible that there exists a vast range of carboniferous strata, reaching for upwards of 1000 miles along the flanks of the Himalaya Mountains, the distance from the mountain chain gradually increasing as we advance westward, the mountains trending northwards and the outcrop of the carboniferous bed southwards, until finally, the distance between them being upwards of 500 miles, the relation is not easily recognised.

I. Commencing with the neighbourhood of Calcutta, we have first to consider the Burdwan coal-district, with which I shall group the Adji and the Rajmahal fields, all these being on the banks of either the Hooghley or Ganges, or on the tributaries of these rivers. The Burdwan district has been long known, and

deal worked. The workable beds of coal are nine and seven feet thick respectively. They are associated with sandstone, shale, and a little clay-ironstone, and about six other thinner seams of coal, while other thick beds are mentioned, but their real existence as separate beds is doubtful. There are now thirteen spots at which this coal is worked, but most of them are surface workings. The deepest sinking is 190 feet. The distance to Calcutta is about ninety miles, but the actual transit of coal is nearly 200 miles. There would seem to be a continuous outcrop of the same kind of rocks from Burdwan up the Adji river, and northwards to Rajmahal. On the Adji river the coal has been worked in more than one spot, and is found to be of about the same quality as that of Burdwan; but neither of them is considered of nearly so good quality as the English coal. Further on, at Rajmahal, coal is known to exist, but has not yet been much worked. The quality of that which has been obtained does not appear good.

II. The Burdwan coal-field appears to be directly connected with a district at Palamow, in which coal has been worked in no fewer than four places. The coal here apparently reposes in a valley inclosed by hills of granite, and is associated with a good deal of iron. There are several beds that are of workable size, but a good deal of the coal is heavy and of inferior quality, and some of it appears to be anthracitic. These coal-beds are not far from the Soane river, and about 100 miles from its confluence with the Ganges, a little above Dinapoor and Patna; but the Soane is not at present navigable. To the west of Palamow the carboniferous beds are described as appearing along two irregular lines, the one towards the south-west for 150 miles, reaching beyond Koorbah, and the other more westward, by Sohagepoor, to the Nerbudda. These beds appear to connect themselves with the Burdwan coal-field; and near Ramgurh coal has been obtained in two or three places. This coal is said to be of very good quality and of considerable thickness; but there can be little doubt that a statement made in the report, of the bed of coal being 200 yards in thickness, must be owing to some misunderstanding of the account and sketch originally communicated. It seems certain, however, from the extent of the outcrop, that the seam must be one of considerable magnitude. Westwards, again, from Palamow, and at a distance of about fifty miles, coal has been found in several places in Singrowli, but the beds at present known are thin; and again, to the south-west, the same mineral occurs at Sirgoojah, where fine coal has been seen, but is not used at present. Between the Singrowli coal and Jubbulpore excellent coal has been found in several places, indicating an extensive coal-field; but the nature and thickness of the beds are not stated.

The Nerbudda district, although from the drainage of the country it belongs to the Bombay side of India, is manifestly more related, so far as the old rocks are concerned, with the Bengal territory. The coal is about 350 miles from Bombay, and the Nerbudda river is at present not navigable. There seem to be three districts in the Nerbudda valley in which coal is found, but the most important of them is that near Gurrawarra, about midway between Hoosungabad and Jubbulpore. The coal here, indeed, appears to be perhaps the best hitherto found in India, and exists in beds three in number, whose thickness respectively is said to be 20 feet, 40 feet, and 25½ feet. There are also other beds, one of which is four feet.

The discovery of this, the Benar coal-field, promises to be of great importance. It is also very near another basin, where there are beds also of excellent quality, one of them six feet in thickness. At Jubbulpore itself coal has been found at a depth of seventy feet, one bed being nearly twelve feet thick.

III. Let us consider now the district east of Calcutta. We there find true carboniferous rocks on both flanks of the Garrow mountains, commencing near Jumalpore, and thence continuing north-eastwards, for a distance amounting on the whole to nearly 400 miles, through Lower and Upper Assam. The district nearest Calcutta is Silhet, on the south flanks of the Garrow, where eleven beds of coal have been determined, whose total thickness as already ascertained amounts to eighty-five feet. This coal is of excellent quality, and can as readily be conveyed to the Upper Ganges as the Burdwan coal. The most remarkable beds occur at Cherra Ponji; but these appear irregular, although they are undoubtedly of great thickness in several spots, amounting sometimes to nearly thirty feet. There are also other important beds. They have been known for more than ten years, but have not been

worked; and since their first discovery large quantities of iron have been smelted with charcoal.

After passing the districts in which the coal has been thus clearly exhibited, we proceed next to the Assam districts, also more or less continuous, and extending for about 350 miles chiefly along the south side of the Burhampooter; the whole being divided into the two groups of Lower and Upper Assam, separated at Bishenath, 170 miles above Calcutta. Six coal-fields are enumerated in the Upper district, and three in the Lower; but the latter, although it would seem not so promising, are looked on as scarcely less important in consequence of their greater accessibility.

So far as details are concerned, the Lower Assam coal offers little positive information; the indications consisting rather of rolled fragments drifted, than of distinct and well-marked beds. It is called lignite in a report from Lieut. Vetch; but both coal and lignite are terms frequently used without reference to any peculiar character of the mineral, or any geological position. Similar beds of coal or lignite to those found in Lower Assam, south of the Burhampooter, are also mentioned as occurring on the north in three of the streams flowing into that river from the Bootan range. The Upper Assam coal is manifestly of great interest, and likely to prove very important. It is associated with abundance of clay ironstone.

About eighty miles above Bishenath, other beds, stated to be six feet thick, have been worked for the sake of trying the œconomic value of the coal. It is described by the commander of one of the Assam Company's steamers, in a letter dated 24th January, 1845, as far the best he ever had on board a steamer, and far superior to any coal in Calcutta. From the growing importance of the tea-trade from Assam, this is likely, therefore, to be of great value. Still further up the country there are several important beds, dipping, it would appear, at so high an angle, and placed so unfavourably with regard to present means of transport, that it would be difficult to work them. The other beds that appear in this district are exposed to the same difficulty; and the coal throughout Northern India appears to be in this respect unfavourably placed.

Passing on now to the other districts in India and the East, in which carboniferous rocks and beds of coal have been met with, I have to enumerate two, the Tenasserim and the Arracan districts, which, from their vicinity to India and their geographical position, are of considerable importance. The former has been known for some years, and there are said to be four localities at which coal appears; but of these only one seems likely to prove of œconomic value. From the accounts given of this coal there is every reason to conclude, that one of the beds is not of the carboniferous period; and although another (on the Thian Khan) has been the subject of a far more favourable report, being called cannel coal, and stated by Mr. Prinsep to be an admirable coal for gas, there is yet much probability of the whole being of the tertiary period. These beds have been described in the 'Journal of the Asiatic Society' for 1838.

In Arracan there are eleven beds of coal, but all of them are thin, and their position nearly vertical. They are said to be associated with sandstones, limestones and shales; but it is clear that they can at present be looked at only as indications, and not of any practical importance.

Notices of some Fossil Mammalia of South America. *By* Prof. Owen, *F.R.S.*

Since the publication of his descriptions of the fossil mammalia collected by Mr. Darwin, the following additional species had come under observation. A new species of the gliriform genus of Pachyderms called Toxodon, was founded on an entire lower jaw, with the intermaxillary part of the upper jaw of a specimen equalling the *Toxodon platensis* in size, transmitted from Buenos Ayres. The new species, which Prof. Owen proposed to call *Toxodon angustidens*, is distinguished by the nearly equal size of the outer and inner incisors of the upper jaw, the transverse diameter of the inner or median one being two inches; and by the narrower transverse diameter of the inferior molars. Prof. Owen considered the characters of this second species of Toxodon as confirming in every respect his ideas of the affinities of the genus expressed by the title, 'Description of the cranium of the *Toxodon platensis*, a gigantic extinct mammiferous animal, referable to the order *Pachydermata*, but with affinities to the *Rodentia*, *Edentata*, and herbivorous *Cetacea*,' under which his original

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In four places the sections are enlarged fourfold, or 40 feet to the inch; and full details are given on the scale of 4 feet to the inch. The colours of the Ordnance Survey are taken as a basis, and others are introduced to describe local facts. The railway passes first through the junction beds of red marl and lias; then for six or seven miles through new red sandstone, interrupted only at one place, where a tunnel, 324 feet in length, pierces the upper beds of the carboniferous limestone; then for about twelve miles chiefly over alluvial tracts, separated by cuttings of new red sandstone beds, also touching the southern margin of the Nailsea coal-field. At twenty-one miles occurs the Uphill cutting, passing through new red sandstone and lias, and then carboniferous limestone, at the base of which is seen some masses of trappean rock. The railway is then carried along an alluvial plain of seventeen miles in length, interrupted only in one place, at three miles north of Bridgewater, by a deep cutting through new red marls and lias at Puriton. From the termination of the alluvial tract to Taunton, the course is over a moderately level country of new red sandstone, and little occurs to attract the attention of the geologist, except the occasional appearance of diluvial gravel, which is seen to contain an increasing proportion of the killas as the observer approaches Taunton. There are four enlarged drawings.

It is desirable to notice first, that called the Ashton cutting, where the carboniferous beds are displayed in three places. Over the two smaller masses and on the sides of the larger one are seen the usual boulder conglomerate, consisting of large and small fragments of limestone, partially water-worn, cemented by the ordinary red clay. As the superincumbent strata are carried over the two small masses of limestone, and apparently tend to ascend over the rock at the tunnel, it might be supposed that a local elevation had taken place subsequent to the deposit of the new red sandstones. This may have been the case, but the inclination and curving of the beds may have been original; and I incline to this opinion, since, on the presumption of the limestone having been elevated by violent force arising from igneous action, the conglomerate adjoining the limestone would have been pierced and thrust aside, and greater displacement manifested in the marly clays above.

At the Uphill section the evidence differs: here not only are violent dislocations of the red marls and lias produced, so that the lias beds dip at an angle of 70° or more towards the plane of intersection between the lias and the limestone, which plane itself dips in the same direction; but, in addition, the igneous rock appears in full force; and it clearly bears relation not only to the fault, which brings into juxtaposition the limestone and lias, but to an extensive fault in the limestone itself, by which the whole series of beds on one side differs from that on the other.

On the nature of the trap rock and its metamorphic influence on the limestone,

Along the watershed, that is to say at the extreme eastern edge of the table-land, several lakes of some magnitude are situate, namely, A'shangi, Háïk and Zuwái; and the great lake Zambézi, or Nyássi, lying further to the south, would appear to be, in like manner, placed near the line along which the minor streams falling into the Indian ocean are divided from those of larger size which flow towards the Atlantic.

The memoir concludes with directing attention to an important practical result which is to be arrived at from this brief survey of the physical character of the Abessinian plateau. "It is, namely, that the eastern coast of Africa presents facilities for the exploration of the interior of that continent very superior to those afforded by the western coast. For, when the narrow belt of low land along the coast of the Indian Ocean—which from its general dryness, arising from the absence of large rivers, is far from unhealthy at most seasons of the year—is once passed and the eastern edge of the elevated table-land is attained, a climate is met with which is not merely congenial to European constitutions, but is absolutely more healthy than that of most countries. Here—that is to say, on the elevated plateau, and not in the low desert country along the sea-coast—travellers might wait in safety, and even with advantage to their health, till suitable opportunities should present themselves for penetrating westward into the interior; and in the event of their having to retrace their steps, they would only return upon a healthy and delightful country. On the other hand, the climate of the western coast is notoriously such, that a traveller is necessitated to press forwards, whatever may be the time of the year, whatever the condition of the country, whatever even his state of health. And should he, from sickness or any other unforeseen circumstance, be compelled to abandon his journey, he must do so with the painful knowledge that the further he retrogrades the more baleful are the districts which he has to traverse and the less likelihood there is of his ever reaching the coast."

Synopsis of a proposal respecting a Physico-Geographical Survey of the British Islands, particularly in relation to Agriculture. *By* W. Desborough Cooley, *Esq.* *Communicated by* Sir R. I. Murchison, *G.C.S., F.R.S.*

1. Physical geography, or that branch of knowledge which treats of natural phænomena and their laws collectively, as they are modified by geographical position, furnishes some of the chief elements of agricultural science. It teaches the relations of comparative climate, without a knowledge of which the results of local experience cannot be safely applied to any extent in agriculture.

2. It is well known that as climate depends fundamentally on the distribution of land and water, on the winds, and is affected probably by other influences not so easily recognised, its changes and gradations deviate widely from the simple rules deducible from geographical position. The lines marking certain degrees of mean temperature, of summer heat and of extreme cold, do not run in parallels of latitude; nor are they parallel to one another, but diverge as we proceed from W. to E.

3. The lines above described, and which are denominated respectively Isothermal, Isotheral and Isocheimal, are, notwithstanding their apparent irregularity, the fixed boundaries of very interesting natural domains; for they mark out the several zones of vegetable life, and the regions suited to the cultivation of different kinds of plants.

4. To the determination of these lines may be added observations of some other phænomena which also contribute to ascertain the conditions of vegetation; as rain, its quantity at different seasons; humidity without rain; the temperature of the earth; its form, conducting and radiating properties, &c.

5. A knowledge of these particulars can only be derived from observations in sufficient number systematically made, and referable to a common standard.

6. The phænomena of physical geography may be considered as determined in a general way for the north of Europe (Denmark), and for the south of Europe also (Italy), by Schouw; and for eastern Europe (Russia) by Baer and Kupffer. For western Europe, or the British Islands, numerous observations of this kind are indeed on record; yet they still want completeness, minuteness, and uniformity; nor has any attempt been made to arrange them systematically with a view to popular use.

7. The anomalies characteristic of the western or oceanic climate increase rapidly towards its furthest limit. There is a wide difference, in respect of climate, between the Isle of Thanet and Limerick or Clare; between Norfolk and Sligo. This is clearly expressed by the changed aspect of indigenous vegetation as we go westwards towards the Atlantic. The exact registration of those differences would be the means of developing and revealing the natural laws to which the labours of the husbandman are unquestionably subject.

8. Where the constants of climate are fully ascertained, the vigorous growth of every kind of plant will be found to be restricted within limits which depend on obvious and assignable conditions, and the region suited to the cultivation of any plant may be accurately defined. Or we may reverse the process and tell the capabilities of any region.

9. But in the absence of this kind of knowledge, agriculture is necessarily founded to a great degree on imitation, without any reference to natural limits. Examples, recommended by success, are followed in situations where similar success is unattainable. Owing to the vague, indeterminate, uncollected and unarranged condition in which the data whereon the agriculturist ought to found his calculations at present lie, he must either practice empirically or imitate servilely; and he is constantly misled by examples, from want of the means of divesting them of fallacy, by estimating accurately the local element of their character. Throughout the British Isles the climate varies far more than the system of agriculture; yet the farmer may reasonably expect to find his labours more profitable the more closely his system harmonizes with nature.

10. The steady progress of scientific agriculture must be preceded by the determination of the constants of climate. The discoveries of the chemist may then be turned to account by the farmer, when we shall be able to state in a definite and authentic manner, the natural conditions of every spot of land in the kingdom.

11. The time is now come when every country must, with a view to profit, strenuously endeavour to confine itself to that kind of cultivation for which nature has especially adapted it; otherwise it must be a loser in the general and free competition. The loss of protection is the loss of an artificial and forced, and therefore, abstractedly speaking, a bad system. If this truth be understood and acted on by the farmer, the result will be an increase of production more than counterbalancing the supposed loss.

12. At the same time there has taken place an increase, in an almost miraculous degree, of the facilities of internal communication, extremely favourable to that more active system of interchange which must be expected to arise whenever agriculturists, quitting the trammels of a uniform routine, learn to take advantage of every natural capability throughout the United Kingdom. It is now no longer necessary or expedient that the farmer should be guided by the demands of the market in his own locality. The east and west can now exchange produce without delay or difficulty, and will, no doubt, frequently find their profit in so doing.

13. In setting forth the demarcations of climate within the British Islands, it would be desirable to enumerate at the same time all the useful plants and objects of culture, in different parts of the world, which seem capable of flourishing within the limits described. This kind of knowledge has a tendency to correct the spirit of routine and obstinately contracted views which render farmers at times so indocile.

14. The constants of climate, with all other physico-geographical data, and the necessary collateral information carefully and clearly arranged, so as to be easily and universally applicable, ought to be published in the cheapest possible form, and *given to the people*.

On the Georama. *By* M. GUERIN.

The author, acknowledging the invention of a Georama to be due to M. Langlard, in 1825, stated the objects he had in view in attempting to execute this great representation of the globe, and the success which he had met with.

M. Guerin had established in Paris this method of teaching geography, by p[ro]traying on a large scale the actual features of the land and sea, and offered reas[ons] in favour of an effort to introduce the georama, and the system of instruction c[on]nected with it, in London.

ZOOLOGY AND BOTANY.

General Observations on the Geographical Distribution of the Flora of India, with Remarks on the Vegetation of its Lakes. By* Prof. ROYLE, *M.D.*

THE author stated, that though the plains of India were generally considered to support only tropical vegetation, yet this differed very much both in the different parts of the country and at different seasons of the year. The plains, moreover, might be distinguished into moist and dry; in the former, embankments were required to prevent inundation; and in the latter, canals for irrigation. In the rainy season, however, most parts supported a tropical vegetation, and rice could be successfully cultivated. So in particular localities, covered with primæval forests, some tropical plants extended even to some of the hot valleys in the neighbourhood of Cashmere. In the cold weather, however, that is in the winter season, some European plants make their appearance in the plains, especially of North-west India; and wheat and barley are as successfully cultivated as in Europe. So in ascending its mountains, especially the Himalayas, every variety of vegetation is met with, almost as much as in proceeding from the equator to the poles, being perfectly tropical at the base, European on the ascent, and polar at the summits of its lofty peaks. The mountains however are also under the influence of the rainy season, and are, indeed, for a great part of the season covered with a canopy of clouds in consequence of the air heated and loaded with moisture in the valleys rising to an elevation where the temperature is below the point of deposition or dew-point. Considerable uniformity of temperature and moisture is produced, in consequence of there being little cooling at night and but little heating during the day, from the sun being unable to penetrate the cloudy canopy, and we therefore see some of the Balsams, Scitamineæ and Orchideæ flourishing at elevations where they could not exist for a day during the dry heat of summer or the piercing cold of winter.

In so extensive a territory and diversified a climate there is necessarily a numerous and a varied flora. The known species of the Indian flora are about 10,000 in number, the majority of course characteristic species, but on the Himalaya of an European type. The vegetation of the different parts of the Indian empire bears a resemblance to that of different countries where there is a similarity of climate, and about 250 species which are found in the plains and mountains of India, also occur in other, some of them very distant parts of the world. The vegetation of different tropical countries is very similar, and they are subjected to the influence of the same physical states. The affinity is very perceptible between the botany of the southern parts of India and that of the Indian Archipelago; the same thing occurs with the flora of southern China; this therefore resembles that of southern India. Mr. Brown long since remarked that about 200 species of the Australian flora are also found in the islands of the southern Pacific as well as in India. Dr. Jack observed at Singapore many remarkable points of coincidence between its productions and those of continental and western India on one hand, and the islands of the Eastern Archipelago on the other; while the prevalence of some Epacrideæ connected it with that of New Holland. The botany of a great part of the drier parts of India has a great resemblance to that of the west coast of Africa, as originally remarked by Mr. Brown, who ascertained that there were about 40 species common to those distant regions. Dr. Royle in the same way remarks a correspondence between the flora of Egypt and that of the drier parts of northern India, and also that some of the characteristic forms of the Mediterranean flora approach its north-western frontier.

The Himalaya mountains have a tropical vegetation at their base and in their valleys. At elevations of 6000 and 7000 feet, the climate is temperate, and the flora corresponds with that of European regions and of the Caucasus, both in its arboreous and herbaceous vegetation, and in the prevalence of many of the same species which are found here in our fields. Among them also are several genera, which, until the last few years, were thought to be peculiar to China, and others to North America.

* This communication was made to the Association at Cambridge in 1845, and was accidentally omitted in the Report for that year.

Several, indeed, of the species are identical with those found in these distant countries, separated on one hand by the cold and arid deserts of Tartary, and on the other by the hot and equally arid plains of India and of Africa, as well as the sea. Some of the peaks however, having the characteristics of polar climates, have also that of the vegetation; and it is curious to see all the families and many of the same genera on these isolated peaks and the remote Melville Island. The northern face of the Himalayas, or the Tibetan region, has the closest resemblance in its genera, and even many of its species, to that of the Atlas mountains and of Siberia, with a sprinkling of the Mediterranean flora. The author, having taken this general view, remarked on the correspondence between the vegetation of even distant countries wherever there was a correspondence in climate, and called attention to the curious resemblance in the belts of vegetation at different elevations on the Himalayas with that of different latitudes, as detailed in the author's 'Illustrations of Himalayan Botany.' Dr. Royle inquired with reference to some of the geological explanations of successive elevations of mountain ranges—at what period the vegetation of the peaks, for instance, came to resemble that of polar regions?

Among the various subjects, Dr. Royle stated, to which he might draw the notice of the Section, there was one, he thought, particularly worthy of the attention of those favourably situated for making observations; and that was the thick vegetation which clothes the surface of many of the lakes of India. Dr. Royle stated that he himself having been chiefly in the north of India, had not seen this vegetation to the extent in which it existed in the more southern parts of India; but even there it was sufficiently substantial to support numbers of the smaller Grallæ, and among them the Chinese Jacana. But having on one occasion been detained on the banks of some of these lakes on the north-west of Bengal, he had been much struck with the thick and varied vegetation of the floating masses with which their surfaces were covered. These consist of numerous stems, leaf and flower-stalks of a variety of plants closely interlaced and matted together, the younger parts requiring both light and air for the performance of their functions, finding their way to the surface; while the older are pushed downwards, when the more herbaceous parts rot and decay. Among these plants are most of the genera and some of the species even, which are found in similar situations in Europe; but with them such plants as *Æschynomene aspera* with its thick cellular stem, *Convolvulus edulis*, *Herpestes Monniera*, and *Utricularia stellaris*, *Marsilea quadrifolia*, *Trapa bispinosa* and *bicornis*, with species of *Polygonum* and *Dysophylla verticillata*. The last is particularly interesting from its long jointed and striated stem with its whorls of leaves. Of most of them it may be observed that they have little or no root; the floating stems are long and slender, very cellular, with the vascular bundles arranged round the circumference, with little or rather with nothing like bark. By Dr. Buchanan Hamilton these lakes have been seen of much greater extent, and covered with a much more dense vegetation, so much so, indeed, that he describes the floating masses to be sufficiently substantial for cattle to graze upon the grasses with which they became covered, but that occasionally some fall through and are lost. He describes, moreover, some bushes and trees as growing in the midst of the water, and among them a Rose, a Barringtonia, and a Cephalanthus.

It is hardly possible to witness such vegetation, without calling to mind some of the explanations given of the formation of coal in the ancient periods of the world, and of the indications often presented to us in coal fields of a tropical vegetation, in situations where no tropical plants could now grow. But without proceeding further, it is interesting to compare the vegetation of these lakes with that of the Indian coal-fields of Burdwan, which are in their immediate vicinity. The first thing that will strike an observer is, that there is no remarkable difference between what was the former flora of these localities, and what might take place at the present day. One great difference is certainly observable in the Indian coal-fields, and that is the immense mass of ferns of which they seem to be composed, while no ferns are at present found in their neighbourhood. This however is owing to the country and the plains of India generally being open, and therefore extremely hot and dry for some months in the year. One fern, *Asplenium radiatum*, is found near Delhi, in the sides of wells, in the peninsula of India, and also in Arabia. *Cheilanthes dealbata* and *Lygodium microphyllum* occur in the neighbouring Rajmuhl hills. But in the same latitude, and not very distant, where the country is covered with forests, producing

shade and moisture, numerous ferns, and even tree ferns are found, as in Silhet. The strata of the Burdwan coal-basins of Ranigunge and Chinakooree yielded the author abundant remains of the Ranigunge reed, *Vertebraria indica*, the marsileaceous genus, *Trizygia speciosa*, and species of Pecopteris, Glossopteris, &c. *G. Browniana* is interesting as having been found in these coal-fields, and according to Brongniart, in New Holland, in the coal of the Hawkesbury river, near Port Jackson. *Zamia Buchanani* has also been found, and a palm which has been called *Zeugophyllites calamoites*. With a little more moisture, or even the umbrageous covering of a forest, these, and other similar plants, would grow with luxuriance in these localities.

Seeing therefore that heat, with moisture, is capable at the present day of supporting a vegetation similar to that of coal-fields, it would in ancient times only have required the presence of heat and moisture for the vegetation of coal-fields to have flourished. If the mass of the earth was in ancient times of a higher temperature, as is inferred from many geological and zoological phænomena, it is evident that, water being present, copious evaporation would necessarily take place as it now does in tropical countries. If the internal heat were uniform at different points of the globe's surface, then would the evaporation be uniform, and there would be an absence of those upper and lower currents of the atmosphere which now carry the heated and moisture-loaded air of the tropics to polar regions, and send the cold air of the latter towards the equator. As the air, loaded with moisture, ascended into the atmosphere, it would at length reach an elevation where the reduction of temperature would proceed beyond the point of deposition of moisture, and the whole of what had been raised by the aid of heat and air would be constantly depositing in the form of clouds and rain. Moisture would thus everywhere be preserved, and the cloudiness from the steady action of the heat below and of the cold above would necessarily also be constant. This would produce uniformity of temperature; for radiation from the surface would be obviated, and the solar rays would not penetrate the cloudy canopy more than they do in rainy weather at the present time. In such a climate, tropical plants would be able to grow equally well in any latitude, and there might be intermixed with them many others to which dryness was not essential. In conclusion, the author remarked, such a cloudy canopy may be observed to a partial extent, even in the present day. Humboldt has described it as occurring on the Andes; the author had himself observed it for days together on the Himalayas, and partially so during the whole of the rains; Dr. M'Clelland and others have described it as occurring for months together in the valley of Assam. If it existed in northern regions in early times, and the sources of heat were, as Dr. Royle assumed, internal, then could tropical vegetation not only exist in polar regions during the summer season, but it would not be destroyed in winter. Growth would only be stopped, as in the present day, during the darkness of night. As the internal heat diminished and receded from the surface, the cloudy canopy would by degrees be at a lower and a lower elevation, until, like the snow-line of the present, it would be at the surface of the earth in high latitudes. These regions would become as they are now, and immediately under the influence of external cold, and thus a glacial might succeed a tropical vegetation. In situations where a lofty peak raised itself above the canopy of clouds, it would become exposed to the cooling effects of radiation, and would, as in the present day, attract to itself and condense much of the floating moisture of the atmosphere, and give origin to mighty and rapid rivers, which would plough the mountain side and overspread the level plain.

A Synopsis of the Classification of the Genera of British Birds. By JOHN HOGG, *M.A., F.R.S., F.L.S., &c.*

The author, having completed his classification of birds, which has been carried out on the same principles as that portion published in the Report of the Fourteenth Meeting of the British Association, although in some respects modified from it, gave in this communication his arrangement of the *genera* of the birds hitherto met with in the *British* Islands.

It will be seen that he has been compelled to increase the *families*, and that he has not inserted the *subfamilies*, esteeming them unnecessary, and as too much lengthening the classification. The author has been very careful in the choice of the

genera, and he trusts it will be found that he has only retained those which are really distinct; and whilst he has, after due consideration, thought it requisite to add to the number of those which British ornithologists usually employ, he has at the same time reduced those too numerous *genera* of certain authors, and especially of the Prince of *Canino*. Likewise, with regard to *subgenera*, the use of which the author must always maintain to be extremely disadvantageous to science, he has wholly omitted all notice of them.

Class II. AVES.

Subclass I. Aves Constrictipedes.

Division I. TERRESTRES.

Order I. Raptores.
- Tribe 1. *Planicerirostres.*
  - Subtribe 1. *Diurni.*
    - Family 1. *Sarcoramphidæ.*
      - Genus *Neophron.*
    - Family 2. *Vulturidæ.*
      - Genus *Gyps.*
    - Family 3. *Aquilidæ.*
      - Genera *Haliaëtus, Aquila, Pandion.*
    - Family 4. *Falconidæ.*
      - Genera *Falco, Accipiter, Astur, Milvus, Nauclerus.*
    - Family 5. *Buteonidæ.*
      - Genera *Buteo, Pernis, Circus, Strigiceps.*
- Tribe 2. *Tecticerirostres.*
  - Subtribe 2. *Nocturni.*
    - Family 1. *Strigidæ.*
      - Genera *Surnia, Nyctea, Strix, Syrnium, Athene.*
    - Family 2. *Bubonidæ.*
      - Genera *Bubo, Otus, Scops.*

*Order III. Insessores.
- Tribe 1. *Curvirostres.*
  - Subtribe 1. *Scansores.*
    - Family *Cuculidæ.*
      - Genera *Cuculus, Oxylophus, Coccyzus.*
- Tribe 2. *Cuneirostres.*
  - Family 1. *Picidæ.*
    - Genera *Dryotomus, Picus, Jynx.*
  - Family 2. *Sittidæ.*
    - Genus *Sitta.*
- Tribe 3. *Conirostres.*
  - Subtribe 2. *Clamatores.*
    - Family 1. *Coraciadidæ.*
      - Genus *Coracias.*
    - Family 2. *Corvidæ.*
      - Genera *Garrulus, Pica, Nucifraga, Corvus, Fregilus.*
  - Subtribe 3. *Cantatores.*
    - Family 3. *Sturnidæ.*
      - Genera *Sturnus, Pastor, Agelaius.*
    - Family 4. *Loxiadæ.*
      - Genera *Loxia, Pyrrhula, Corythus, Coccothraustes.*
    - Family 5. *Fringillidæ.*
      - Genera *Passer, Linota, Carduelis, Fringilla.*
    - Family 6. *Emberizidæ.*
      - Genera *Emberiza, Plectrophanes.*
    - Family 7. *Alaudidæ.*
      - Genera *Phileremus, Alauda, Galerida.*
- Tribe 4. *Dentirostres.*
  - Family 1. *Anthidæ.*
    - Genus *Anthus.*
  - Family 2. *Motacillidæ.*
    - Genera *Budytes, Motacilla.*
  - Family 3. *Paridæ.*
    - Genera *Calamophilus, Mecistura, Parus.*
  - Family 4. *Ædonidæ.*
    - Genera *Regulus, Melizophilus, Sylvia, Curruca, Aëdon, Salicaria, Accentor.*
  - Family 5. *Saxicolidæ.*
    - Genera *Phœnicura, Erithacus, Saxicola, Vitiflora.*
  - Family 6. *Ampelididæ.*
    - Genus *Bombycilla.*
  - Family 7. *Merulidæ.*
    - Genera *Oriolus, Hæmatornis, Turdus, Petrocincla, Merula, Cinclus.*
  - Subtribe 4. *Latrones.*
    - Family 8. *Laniadæ.*
      - Genera *Lanius, Collurio.*
    - Family 9. *Muscicapidæ.*
      - Genus *Muscicapa.*
- Tribe 5. *Tenuirostres.*
  - Subtribe 5. *Anisodactyli.*
    - Family 1. *Certhiadæ.*
      - Genera *Troglodytes, Certhia.*
    - Family 2. *Upupidæ.*
      - Genus *Upupa.*
- Tribe 6. *Fissirostres.*
  - Subtribe 6. *Syndactyli.*
    - Family 1. *Halcyonidæ.*
      - Genus *Alcedo.*
    - Family 2. *Meropidæ.*
      - Genus *Merops.*

* The author's Order II. *Prehensores* entirely consists of foreign birds, which belong to Genus *Psittacus* of Linnæus. His proposed divisions of this order are given in James Edinburgh Phil. Journal for July, 1846.

Subtribe 7. *Allodactyli.*
Family 3. *Hirundinidæ.*
Genera *Cypselus, Progne, Hirundo, Chelidon.*
Family 4. *Caprimulgidæ.*
Genus *Caprimulgus.*
Tribe 7. *Cutinarirostres.*
Subtribe 8. *Gyratores.*
Family *Columbidæ.*
Genera *Columba, Turtur, Ectopistes.*

Subclass II. Aves Inconstrictipedes.

Order IV. Rasores.
Tribe *Convexirostres.*
Subtribe 1. *Podarcees.*
Family 1. *Phasianidæ.*
Genus *Phasianus.*
Family 2. *Tetraonidæ.*
Genera *Tetrao, Lagopus.*
Family 3. *Perdicidæ.*
Genera *Perdix, Ortyx, Coturnix.*
Family 4. *Hemipodiadæ.*
Genus *Hemipodius.*
Subtribe 2. *Podenemi.*
Family 5. *Otididæ.*
Genus *Otis.*

Division II. AQUATICÆ.

Order V. Grallatores.
Tribe 1. *Pressirostres.*
Subtribe 1. *Cursores.*
Family 1. *Charadriadæ.*
Genera *Œdicnemus, Cursorius, Charadrius.*
Family 2. *Vanellidæ.*
Genera *Squatarola, Vanellus, Glareola, Strepsilas.*
Family 3. *Hæmatopodidæ.*
Genus *Hæmatopus.*
Tribe 2. *Cultrirostres.*
Subtribe 2. *Ambulatores.*
Family 1. *Gruidæ.*
Genus *Grus.*
Family 2. *Ardeidæ.*
Genera *Ciconia, Ardea, Ardeola, Erodias, Nycticorax.*
Tribe 3. *Spathulirostres.*
Family *Plataleidæ.*
Genus *Platalea.*
Tribe 4. *Longirostres.*
Family 1. *Tantalidæ.*
Genus *Ibis.*
Family 2. *Recurvirostridæ.*
Genus *Recurvirostra.*
Family 3. *Numeniadæ.*
Genera *Limosa. Numenius.*
Family 4. *Scolopacidæ.*
Genera *Totanus, Machetes, Rusticola, Scolopax, Macrorhamphus, Tringa.*
Family 5. *Phalaropodidæ.*
Genera *Phalaropus, Lobipes.*
Family 6. *Calidridæ.*
Genera *Himantopus, Calidris.*
Tribe 5. *Diversirostres.*
Subtribe 3. *Macrodactyli.*
Family *Rallidæ.*
Genera *Rallus, Crex, Zapornia.*
Tribe 6. *Fronticutirostres.*
Family *Fulicidæ.*
Genera *Gallinula, Porphyrio, Fulica.*

Order VI. Natatores.
Tribe 1. *Lamellirostres.*
Subtribe 1. *Simplicipollices.*
Family 1. *Anseridæ.*
Genera *Bernicla, Anser, Cygnus, Plectropterus, Chenalopex.*
Family 2. *Anatidæ.*
Genera *Tadorna, Rhynchaspis, Chauliodus, Dafila, Anas, Marecca.*
Subtribe 2. *Membranipollices.*
Family 3. *Fuligulidæ.*
Genera *Clangula, Harelda, Fuligula, Œdemia, Somateria.*
Tribe 2. *Serrirostres.*
Family 1. *Mergidæ.*
Genera *Mergus, Merganser.*
Subtribe 3. *Totipalmæ.*
Family 2. *Carbonidæ.*
Genera *Carbo, Sula.*
Tribe 3. *Tubinarirostres.*
Subtribe 4. *Longipennes.*
Family *Procellariadæ.*
Genera *Procellaria, Puffinus, Thalassidroma.*
Tribe 4. *Mediocrirostres.*
Family *Laridæ.*
Genera *Cataracta, Lestris, Larus, Rissa, Xema.*
Tribe 5. *Subulirostres.*
Family *Sternidæ.*
Genera *Anous, Viralva, Pontochelidon, Sterna.*
Tribe 6. *Cuspidirostres.*
Subtribe 5. *Brevipennes.*
Family 1. *Podicipidæ.*
Genus *Podiceps.*
Family 2. *Colymbidæ.*
Genera *Colymbus, Uria.*
Tribe 7. *Sulcirostres.*
Family 1. *Mormonidæ.*
Genera *Mergulus, Mormon, Utamania.*
Subtribe 6. *Imperfectipennes.*
Family 2. *Alcidæ.*
Genus *Alca.*

List of the Names of Periodical Birds, and the dates of their appearance and disappearance, at Llanrwst, in North Wales. By JOHN BLACKWALL, *F.L.S.*

Mr. Gould exhibited several new species of humming-birds from the Andes.

On the Figures of Birds observed on a Tomb at Memphis. By J. BONOMI.

Since his last communication the author had received the following note from Mr. Moreing:—"The gigantic nests to which you refer, were seen by me in the years 1829 and 1830, during the time I was attached to the Surveying Expedition in the Red Sea. I do not remember having seen them to the south of Cossier, but to the north of that town, and about the entrance to the Sea of Suez, I observed many. They were always situated on the small sandy spits and islands with which the Red Sea abounds; but you are mistaken if you suppose them to be entirely the work of the birds which breed in them. They varied both in size and height, and were evidently formed in the first instance by the wash of the sea heaving up pieces of broken coral, drift wood, and other rubbish on the extremity of a sand spit. The birds added to the mound thus formed; and placed their nests on the top, to protect themselves from the spray in rough weather. I am not clear as to the species of bird which make use of these singular nests, but believe that more than one kind of gull avail themselves of the security thus offered."

On the Crania of two species of Crocodile from Sierra Leone. By H. FALCONER, *M.D.* and W. THOMPSON*.

Crocodilus cataphractus, Cuv. and *C. vulgaris*, Cuv. (var. C. Dumeril and Bibron), were the species noticed; the cranium of the former, divested of its integuments, being now for the first time described. The differences between the cranium of the latter and that of allied species were noticed in detail in the paper, which was illustrated by figures of the crania of the two forms from Sierra Leone, whence the specimens were brought by Dr. M'Cormac of Belfast, and presented by him to the museum of that town.

Recollections of Researches into the Natural and Economic History of certain Species of the Clupeadæ, Coregoni, and Salmonidæ. By R. KNOX, *M.D.*

The author stated that his object was to bring before the Association, and afterwards before the Academy of Sciences of Paris, a brief view of the inquiries made by himself and his brother into the natural history of certain important gregarious fishes. His discovery that the food of the Vendace or Vengis, of Lochmaben, consisted exclusively of the minute, or rather microscopic Entomostraca inhabiting the lakes of Lochmaben, was first communicated to the Royal Society of Edinburgh. This discovery, which at the time appeared to the author and to a few others of the highest importance in natural history science, had, in his opinion, been misunderstood by the public, and by most naturalists to whom he had spoken; they adhering to the old opinion, that certain fishes, to be afterwards spoken of, preyed on the Entomostraca merely occasionally; at other times on small shell-fish, animalcules, minute or small fishes, &c., just as they could get them: which opinions the author endeavoured to show were contrary to the facts. After discovering that fishes so numerous, so productive and of such a size as the Vendace, subsisted solely on one description of food, the Entomostraca,—a sort of food over which man can exercise little control, especially in the ocean,—the author knowing that, up to his time, the real food of the herring and of several other species of fish had never been discovered, prosecuted his inquiries into this important branch. The result was the discovery that, whilst the Vendace lives exclusively on the Entomostraca, the same may be said of the herring; that is, of most of its varieties. The finer kinds of trout, also the Char, live chiefly on the Entomostraca. Dr. Knox gave an outline

* Published in full, accompanied by illustrations, in the Annals of Nat. Hist. for Dec.

a superior kind of trout, which he thinks has not been described by naturalists: he calls it the "Estuary Trout," brackish waters being the locality it prefers. Its food differs from all others he has examined. Should it prove, on future inquiry, that the brackish water is the limit to its usual, or natural range, it may furnish a means of deciding on some difficult legal questions. As regards the celebrated questions raised by the Drumlanrig experiments, to which his first memoir gave, as he believes, the exciting cause, Dr. Knox thinks it not proved that the salmon smolt, that is the young salmon, ever remains longer in the river than a few weeks after rising from the gravel; and thinks that the opinions founded on the Drumlanrig experiments are in this respect erroneous. 2nd. As regards the question of the parr, no new fact was added to its previous history by these experiments; the *parr markings*, which may be again made visible on scraping off the scales of the smolt, was a fact well-known to anglers; who at the close of the day found it difficult to say which were true parr and which salmon smolts. Mr. Scrope first gave a beautiful drawing of this fact. 3d. For at least a hundred years the opinion that the parr was the young of the salmon prevailed universally in Annandale. 4th. Willoughby had proved that the salmon-egg may be impregnated by the milt of the parr; an experiment curious enough physiologically, but otherwise of no practical importance. 5th. Mr. Hogg and a great many others had marked the spring parr, and found that they returned to the rivers full-grown salmon. Thus no new fact was added to the natural history of the salmon by the Drumlanrig experiments. The author declined giving a decided opinion as to the real nature of the true parr; but, so far as his observations had yet gone, he believes that there is a fish which may be called the *true parr*, hitherto confounded with many other species having *parr markings*; and that this *true parr* may ultimately prove a hybrid between the salmon or salmon trout and certain species of river trout.

On the Application of the Method, discovered by the late Dr. Thibert, of Modelling and Colouring after Nature all kinds of Fishes. By R. Knox, *M.D.*

These models were shown. They consisted of the Vendace, the mackerel, the red-spotted trout of England, and the Lochmaben trout. This method of modelling will ultimately be preferred to all others; even to that in wax.

On the Egg-purse and Embryo of a Species of Myliobatus. By J. Couch, *F.L.S.*

The author commenced by stating that the egg-purse was found in August 1845, in the refuse of a trawl-boat by Mr. Peach; and was obtained a few miles south of Fowey, in Cornwall. After mentioning how little is known of the egg-cases of the rays and sharks, he minutely described it; and showed the difference between it and others, particularly dwelling on the structure of the surface, it being reticulated, whereas all the other egg-purses are smooth. In the egg-purse was a living young fish, which proves to belong to the genus Myliobatus of Cuvier, characterized by having the pectoral expansion separated from the head. These, from the direction of the wings, have been fancifully called sea-eagles. Ruysch, whose figures are for the most part copies from preceding authors without being improvements on the originals, but who, at plate 9. fig. 9, has given one tolerably characteristic, remarks that it has been called "Sea Toad," from the form of the head resembling that creature; and the comparison seems appropriate, from the elevated head with a protuberant and lateral eye. The same author says that this fish is viviparous; an assertion which the foregoing account shows to be incorrect.

On the Crustacea found by Prof. E. Forbes *and* Mr. M'Andrew *in their Cruises round the coast. By* Prof. Thomas Bell, *F.R.S., F.L.S. &c.*

Having been requested by my friends Prof. Forbes and Mr. M'Andrew to communicate to the Section some observations on the contributions to carcinology made by those gentlemen in [illegible]nt cruises, I gladly comply with their wish; and although I have not [illegible]y actual novelties in the species collected, yet

several interesting facts have been established which may be of future importance in their collateral bearing upon matters of more general interest and importance than the mere discovery of isolated species or forms. In regard however to one entirely new form, there are some points of peculiar interest to which I shall presently take an opportunity of referring.

I have thought it best to consider the species procured under three heads. Of the species found in the northern cruises of Mr. M'Andrew, in the first instance alone, and afterwards accompanied by Prof. Forbes, I will enumerate those found in water under twenty fathoms; and secondly, those in water above that depth; and thirdly, those which have been found in the excursion which these gentlemen have recently concluded along the south-western coast. The following is the list of the more interesting species found principally in Loch Fyne, in water under twenty fathoms. Of the natatorial type of the Brachyura we have only two species, *Portunus corrugatus* and *depurator*; and amongst the Macrura, *Pandalus annulicornis*, and a new species of Hippolyte, to which I propose to give the name of *H. MacAndreæ*. In deeper water the forms are more interesting. In Loch Fyne we have *Ebalia Pennantii*; off Zetland *Ebalia Cranchii*, a species first discovered on the south-west coast; *Eurynome aspera* occurs off the Isle of Man; *Atelecyclus heterodon*, *Lithodes arcticus* in Loch Fyne, off the Isle of Man, and off the coast of Zetland; *Galathea nexa* and its near ally *Munida Rondeletii* (*G. rugosa* of authors), both in deep water off Zetland and in Loch Fyne; and here I would make a remark or two on these two species. The localities in which they were found upon this occasion prove them both to be deep sea species, which other observations have also shown. I would also remark that the possession of a new species closely allied to our native species of Leach's genus *Munida*, procured by my friend Mr. Darwin in his voyage, clearly shows the propriety of Leach's having separated generically the *Galathea rugosa* from the other species of that Fabrician genus; and as the latter is absolutely more rugose than the species originally so designated, I have thought it proper to assign to it a new specific appellation, and have given it that of *Rondeletii*, after the first naturalist who distinguished and figured it. Of *Galathea nexa* I have only to remark, that there is no one character to indicate any difference in its habits from its immediate congeners, *G. squamifera* and *strigosa*, and yet both the latter are shore species, where, as far as I know, *G. nexa* is always found in deep water. On the latter species was found a parasite of the genus *Bopyrus*, which will probably prove to be a new species. *Crangon Cataphractus* (*Pontophilus spinosus* of Leach) was found off Zetland, and to these I have to add *Leachia lacertosa* of Johnston. But by far the most interesting of all the acquisitions of my friends in their northern cruises, is the discovery of an entirely new genus of the fossorial type of the Macroura, belonging to the family of the Thalassinidæ, but differing in many important characters from all known genera of that group. In the first place, instead of the monstrous and abnormal character of the first pair of thoracic members, we find them here of nearly the normal construction of the higher and more typical macrourous forms. But the most remarkable circumstance connected with this animal has yet to be mentioned. It was found in one instance at the depth of no less than 180 fathoms, and as at this great depth it is also fossorial amongst sandy mud, we can scarcely imagine of what use any organs of vision could be to an animal so situated. I find accordingly, that although it possesses eyes, they are of no avail as organs of distinct vision, as they possess no pigment, nor, as far as I have observed, have they corneæ; and I presume that the other parts essential for high powers of sight are also wholly wanting. Amongst a collection of the crustacea of the coasts of Ireland, formed by Mr. Thompson, and which he has obligingly placed in my hands, I found a pair of peculiar claws of some species of crustacea with which I was wholly unacquainted; they were taken from the stomach of some deep-water ground-feeding fish, and I now discover that they belong to the species in question. Mr. M'Andrew took it alive in Loch Fyne and the Mull of Galloway, by the dredge; and that gentleman and Prof. Forbes afterwards obtained it off Zetland.

The recent cruise of my friends round the western coast has been fruitful in the acquisition of species of interest, although only one addition has been made by it to the list of English crustacea. The more usual species, *Stenorhynchus tenuirostris* *Atelecyclus heterodon*, *Portunus depurator* and *pusillus*, *Gonoplox angulata*, *Eurynom*

aspera, and *Ebalia Pennantii*, require only to be enumerated. *Xantho rivulosa*, recently discovered to be a British species, is also included. In addition to *Pagurus Prideauxii*, I find also two of the new species of Pagurus, which I have recently described; of these two, *P. lævis* was first discovered by Mr. Thompson on the Irish coast; the other was found off Plymouth by Mr. Cocles, and first described by me under the name of *P. Forbesii*. *Lithodes arctica*, a northern form, is also in the present collection; but the most interesting amongst the fruits of this little expedition is a fine specimen of a species of the natatory type of the Brachyura, a Portunus entirely new to our fauna, and which appears to me to be *P. longipes* of Risso, a Mediterranean species. It differs from the only specimen I have in my collection of the latter species, but this may arise from my Mediterranean specimen being very young.

On the Structure of the Pycnogonideæ. By Dr. CARPENTER.

The President exhibited a specimen of a beetle (*Blaps mortisaga*), which has been found imbedded in some artificial concrete, where it must have been at least sixteen years; and yet, when the animal was brought to him, it was alive, and lived for six weeks after.

Dr. Carpenter gave an account of his researches on the microscopic character of shells, and also the results of his attempts at representing natural history objects by means of photography.

On the Dissimilarity in the Calcifying Functions of Mollusks, whose organization is in other respects similar. By L. REEVE, *F.L.S. &c.*

Each of the four shell-secreting kinds of Cephalopods—the Cuttle-fish, the Paper Nautilus, the Pearly Nautilus, and the Spirule or Ram's Horn—exhibits a different method of forming its shell, (this shell differing in microscopic structure, and secreted from different parts of the system,) although strictly allied in all those elements of anatomical detail which constitute the soft parts or animal frame. Whilst the calcareous portion of the Cuttle-fish is merely represented by an internal bony plate, consisting mainly of carbonate of lime, the shell of the Pearly Nautilus constitutes a huge mechanical apparatus, secreted from the mantle enveloping the visceral mass, and consisting of two separate deposits—an outer crust, and an inner nacre—for the purpose of buoying up its inhabitant under the different mutations of pressure to which it is subjected in its deep region of habitation. The shell of the Paper Nautilus, on the other hand, is a light elastic boat, transparent and permeable to light, secreted only by the female for the purpose of oviposition; and in this animal the office of calcification is transferred, by some mysterious order, from the mantle to the hinder pair of arms. The Spirule is again totally different, it being contained within the mantle of an animal, far larger, in proportion, than that of the other Cephalopods, under circumstances which are at present unknown. The drawing exhibited was taken from a living specimen, recently collected at New Zealand, by Mr. Earl, for the first time in perfect condition; but, as the proprietor is unwilling that it should be dissected, Mr. Reeve could only state that it enclosed a problem in the physiological history of the Cephalopods, which it was extremely desirable to solve. The next point to which he directed the attention of the Section was the curious difference which occurs in the growth of the Cowry and the Olive; but this he had already more fully communicated to the Linnean Society.

On certain Peculiarities in the Anatomy of Limax Sowerbii. *By* Prof. ALLMAN, *M.R.I.A.*

The peculiarities of structure in this animal are chiefly to be found in the reproductive system, which in several respects presents a remarkable similarity to that of *Helix*. There are well-developed *multifid vesicles*, and an elongated sac containing a singular organ in the form of a curved cylinder beset with numerous palmate spines.

This sac, as well as the multifid vesicles, of which there are four sets, opens into the common sac of generation.

Notices of some new and rare British species of naked Mollusca. *By* JOSHUA ALDER *and* ALBANY HANCOCK.

The first species was a small mollusk belonging to the order *Inferobranchiata*. This animal closely resembled the animals figured by M. de Quatrefages under the generic names of Pelta and Chalides, and placed by him as the lowest forms of his new order, *Phlebenterata*. This animal strongly resembles the *Limapontia nigra* of Dr. Johnston; but whether it be identical with that animal or not, the authors were fully convinced that its characters had been imperfectly understood by M. de Quatrefages. The other naked mollusks found by the authors were a new species of *Eumenis*, *Eolis Drummondi*, *Eolis alba*, and *Goniodoris castanea*.

On the Hybernation of Snails. *By* Rev. T. RANKIN, *M.A.*

From the author's observations on the habits of *Helix hortensis*, he concluded,—1. That snails hybernate. 2. That in their state of hybernation they undergo less torpor than some other animals which hybernate. 3. That they are destructive to trees as well as to plants.

Mr. Wollaston read a notice from Mr. William King of some new species of animals found on the coast of Northumberland.

Mr. R. Patterson exhibited specimens of Ascidians which he had discovered in the links of the chain of the floating bridge at Itchin, near Southampton,

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A few Notes on the Land Mollusca, Zoophytes, and Algæ of the Isle of Wight. *By* W. THOMPSON.

The object of this communication was to inform naturalists visiting the island what species they might expect to find in the classes indicated, which are less known than the other departments of its natural history: lists of these were given. Rare and interesting species were noticed, and the localities where they had been obtained by the author particularized. Freshwater Bay and the adjacent coast to the east of it, were stated to be the best localities for the marine invertebrate animals and Algæ. Of land mollusca; the *Pupa secale* and *Bulimus acutus* were specially noticed. Of Zoophytes; the *Anguinaria spatulata* was found commonly investing the stems of various Algæ on the south coast of the island. Of Algæ; the *Griffithsia simplicifilum* was obtained plentifully at Freshwater Bay, in August 1841, by Mr. R. Ball and the author—the first time of its being noticed elsewhere in the British island, than on the coast of Wicklow.

Additions to the Fauna of Ireland, including Species new to that of Britain. *By* W. THOMPSON*.

These additions comprised about fifty species of vertebrate and invertebrate animals. Those unrecorded in the British Fauna were the purple water-hen (*Porphyrio hyacinthinus*), obtained in the county of Kerry by Richard Chute, Esq.; the *Tellina balaustina*, and *Pleurotoma striolata*, both known as Mediterranean species—the former procured by Mr. Barlee, the latter by Mr. M'Andrew, on the western coast of Ireland; *Botrylloides albicans* (Edw.), and *B. rotifera* (Edw.), collected on the coast of Down, by the author; and *Pontobdella lævis* (Blainville). A new *Actinia* of the genus *Corynactis* (Allman) was noticed; and two new species of *Amorphozoa* (Sponges), and a *Daphnia*, believed to be undescribed, were stated to have been obtained. "*Dysidea? papillosa*" (Johnston), whose place in the system had been uncertain, was lately ascertained by the author to be a helianthoid zoophyte, of the genus *Zoanthus* (*Z. Couchii*).

* Published in detail in the Annals of Natural History for Nov. and Dec. 1846 (vol. xviii.

Zoology of Lough Neagh, compared with that of the Lake of Geneva. By W. THOMPSON; *the Insects by* A. H. HALIDAY.

The respective areas of Lough Neagh and the lake of Geneva, and their physical, &c. differences being first noticed, a comparison was given of as many portions of the subject as the published memoirs on the zoology of the Swiss lake afforded data on, including the birds, fishes, mollusca, and certain families of the insects. A brief notice of the *Crustacea* and *Annelida* of Lough Neagh, and some remarks on the botany of its shores and waters, concluded the paper.

Notes on the Natural History of Corfu. By Captain PORTLOCK, *R.E.*

On the Pulmograde Medusæ of the British Seas. By Prof. E. FORBES.

At the Birmingham Meeting, in 1839, the author, in conjunction with Prof. Goodsir, brought forward a first essay towards an investigation of the British Acalephæ, selecting the ciliograde species for illustration. Since that time he has yearly availed himself of every opportunity of pursuing the inquiry, but has abstained from publishing, hoping to gain more complete knowledge of a difficult and much-confused branch of zoology. Having now however examined more than twice the recorded number of British Medusæ and become acquainted with numerous new specific and several new generic forms of great interest to the naturalist, he ventures to lay before the Section an outline of the data in his possession. These data are in great part due to the opportunities afforded him by his voyages round the coasts of Britain with his friend, Mr. M'Andrew. After pointing out the difficulties attending the study of these animals, and giving a brief view of the present state of the subject generally, Prof. Forbes insisted on the necessity in future of naturalists abstaining from publishing imperfect observations respecting them, and urged the adoption of the descriptions of Milne-Edwards, Sars, and Will as models for those who were ready seriously to engage in the study. He called attention to the important observations on their development lately made by his friend Prof. Reid of St. Andrews, and expressed a hope that ere long the return of the Arctic Expedition would bring a great mass of new materials of the most accurate description through the observations of Mr. H. Goodsir. In grouping the British species, Prof. Forbes calls attention to the mutual correspondence of certain characters; viz. of the condition of the reproductive, digestive, and sensitive systems. He proposes to group all the British Medusæ under such as have hooded and such as have naked ocelli. The first character is combined with a conspicuous and comparatively complicated reproductive system, and a ramified gastrovascular apparatus. All the Pulmograda with naked ocelli have simple vessels, with one exception,—a new and most beautiful generic form, the type of a subsection by itself. The remainder form three natural groups, as will be seen in the following general table, exhibiting the arrangement of the British Pulmograde Medusæ:—

1st SECTION.—Hooded-eyed; ramified gastrovascular system.

1st Genus.—*Rhizostoma* (Cuvier). 1 species, *R. Aldrovandi.*

2nd Genus.—*Cassiopea* (Peron). 1 sp., *C. lunulata.*

3rd Genus.—*Pelagia* (Peron). 1 sp., *P. cyanella*, one of the most phosphorescent and beautiful of European Medusæ, now first announced as British, having been taken during the past month by Mr. M'Andrew and Prof. Forbes off the coast of Cornwall.

4th Genus.—*Chrysaora* (Peron). 1 sp., *C. hysoscella.*

5th Genus.—*Cyanea* (Peron). 2 sp., *C. capillata* and *C. Lamarckii*, both common; very large, stinging Medusæ.

6th Genus.—*Medusa* (Linnæus, Eschscholtz—Aurelia, Peron). 2 sp., *M. aurita* and *M. cruciata* (the latter is the Medusa so abundant in Southampton Harbour). It has white ocelli.

Many more spurious species of Cyanea, Medusa, and other genera are recorded by Peron, Lesson, and others, and enumerated as inhabitants of the British Channel. After careful consideration, they have been rejected as mere varieties from this

arrangement. Certain forms belonging to this section recorded by Pennant and Templeton are also rejected as too imperfectly observed to be of any service to science.

2nd Section.—Pulmograda with naked ocelli.

1st Family.—Vessels branched.

7th Genus.—*Willsia* (new, sp. *W. stellata* founded on a beautiful little Medusa with six starlike ovaries and branched vessels. It is abundant in the British Channel and on the west coast of Scotland.

2nd Family.—Vessels simple; ovaries convoluted and lining the pedunculated stomach.

8th Genus.—*Turris* (Lesson; Eirene, Eschscholtz), 2 sp., *T. digitale* of O. Fabricius (Zetland) and *T. neglecta*, Lesson, the *Cyanea coccinea* of Davis; British Channel. Very highly-organized Medusæ, closely approaching Actineæ.

9th Genus.—*Saphenia* (Eschscholtz). 1 sp., *S. dinema*, Peron. Devon, Zetland.

10th Genus.—*Oceania* (Peron—Tiara, Lesson), 4 sp., one being the *Geryonia octona* of Fleming; the other three are new.

3rd Family.—Vessels simple, ovaries in the course of the vessels, on the subumbrella.

a. With eight vessels.

11th Genus.—*Æquorea* (Peron), or perhaps deserving of a distinct appellation; 1 sp., common on the Scotch coast; it is the "*Milicertum campanulatum*" of Ehrenberg (not of Eschscholtz), "*Oceania octocostata*" of Sars, and "*Thaumantias Milleri*" of Mr. Landsborough, and "*Æquorea octocostata*" of Lesson. It has long yellow ovaries.

12th Genus.—*Circe* (Mertens). Ovaries 8 minute. 1 sp., *C. rosea*. Zetland, new.

b. With four vessels.

14th Genus.—*Thaumantias* (Eschscholtz); ovaries four, ovate, clavate or linear, stomach short; 19 British species, of which 12 are new and undescribed. All very distinct from each other.

15th Genus.—*Slabberia* (new), founded for a singular little Medusa remarkable for its extremely linear ovaries, long proboscis, and the development of an ocellated bulb at the end as well as at the base of each tentacle, *S. halterata*; coast of Cornwall.

16th Genus.—*Geryonia* (Peron), 1 sp., new, *G. appendiculata*. British Channel.

17th Genus.—*Tima* (Eschscholtz?)—*T. Bairdii* of Johnston; common on the east coast of Scotland.

4th Family.—Vessels simple; ovary in substance of peduncle. Gemmiparous.

A. Peduncle with lateral lobes; tentacula fasciculated.

18th Genus.—*Bugainvillia* (Lesson—*Hippocrene* Brandt), with 4 fascicles of tentacles. 3 sp., 2 new.

19th Genus.—*Lizzia* (new, with 8 fascicles of tentacles and unequal lobes to peduncle), founded for the *Cytalis octopunctata* of Sars, which, with two other undescribed species, inhabits the Zetland seas.

B. Peduncles inflated; tentacula not fasciculated.

20th Genus.—*Moodeeria* (new). 1 sp. from the Hebrides.

C. Peduncle elongate; tentacula not fasciculated.

a. With four tentacles.

21st Genus.—*Sarsia* (Lesson). 4 British sp.

b. With one tentacle only developed.

22nd Genus.—*Steenstrupia* (new), 3 sp.

In all there are fifty species of British Pulmograda known to Prof. Forbes, excluding doubtful forms and varieties. Of these, fifty-nine only had been previously recorded as British, and of the remainder all but five are undescribed.

Prof. Forbes also exhibited some living specimens of the Lancelot (*Amphioxus lanceolatus* of Yarrell), of a Holothuria, and of a Medusa found in the Sou[illegible] Water.

On the Marine Zoology of Cornwall. *By* C. W. Peach.

The Author had added several new zoophytes to our Fauna—one Actinia new to the British Islands, and named by Dr. Johnston *Actinia chrysanthellum*. It buries itself in sand under stones in Fowey Harbour; and has twelve tentacula. Several calcareous Corallines have been also observed, differing from all that are at present figured. He exhibited, also, a beautiful series of the rare *Echinus Flemingii*; and a magnificent specimen of *Echinus sphæra*; also another large and fine specimen, which, if not a new species, differs much from all others, and requires a careful examination; he had noticed it in various stages of growth. After noticing the Eolides and Annelides, he mentioned the circumstance of having got the *Gymnolepas Cuvieri* from the bottom of a vessel which came into Fowey Harbour in January of the present year; and after minutely describing it, showed that although exposed to the full influence, for one month, of the freshwater which passed down the harbour on the receding tide, it continued to thrive long after the whole of the common Barnacle, which accompanied it, had ceased to exist.

A paper was read from Dr. Bell Salter, giving directions for the guidance of botanists in their excursion to the Isle of Wight, and giving a list of flowering plants of interest found in various parts of the island.

On the Embryogeny of Pulmogrades and Ciliogrades. *By* John Price, *M.A.*

About the end of June 1845, a great number of the ova of *Cyanea aurita* and *Medusa capillata*? (*Stinger*) were collected from *domesticated* specimens, and kept in sea-water. After moving about for a few days, as ciliated pear-shaped germs, they became more sedate; assumed first a square, and then an *octagon* form; gave out tentacles from each angle; "produced" the convex surface into an adhesive peduncle; and, being attached thereby to the glass, appeared ever after as whitish *Hydras*. I was not then aware of the metamorphoses recorded by Sir I. Dalzel, Sars, or others; but was soon informed of them by friends who saw these larvæ. During eighteen weeks I looked earnestly (but *sceptically*) for the fissiparous or gemmiparous reproduction alleged by others, but *in vain*. *Subtraction* was the only rule worked in this "Infant School" of mine: of Addition, Multiplication or Division they seemed to know *nothing*. By October 4 the countless host were reduced to *three*; which, though trebled in *size*, had not undergone the slightest change in form from the zoanthoid type first assumed. I need not send *figures* of them, as several scientific friends have pronounced my drawings *exactly* like those of previous observers, including now *Steenstrup*. However, about the same time, a single (much larger) individual was discovered adhering to one of the *other* jars. Under a lens, this had every appearance of being a *compound* zoophyte; in time, five or six separate individuals were found to have clustered round the original centre; and subsequently, some of these having *apparently* enlarged and separated, the number by June 1846 amounted to more than thirty, *all very near to the same spot*. I say "*apparently*" separated, as there was not sufficiently exact attention bestowed upon the phænomena to remove, *from a sceptic, all* doubts whether the clusters were more than parasitic adhesions (as in *Actinia*, or *Tubularia indivisa*), or whether the new individuals might not have emerged from the sand and other rubbish in the jar, during unobserved intervals. But I must confess I am *all but* satisfied that veritable reproduction *has repeatedly* occurred. At this moment (about eleven months from the discovery of the single larger Hydra) I am able, amidst much rubbish which I am afraid to remove, to count thirty-five, *after several* losses. One is at least three times the average size, and shows, if I mistake not, a *six*-sided mouth (an anomaly, perhaps, portending an approaching change) with *about* thirty-two tentacles surrounding, in single row, a *considerable circum-oral* area. Every one of them remains as true a *zoanth* as ever. Some minute turbinates in the same jar are constantly falling a prey to these "monsters of the deep," and may be seen hanging in chains, or engulfed in the stomach [illegible] floor is strewed with empty shells. I have

observed *no* difference between the embryos of the *Cyanea* and *Med. capillata?* (*Stinger*) after they lost their respective colours (lilac and tawny) and became digitate. Both alike make little cruises and rotate, before they fix themselves: *both* affect the form of a fist with one or two fingers extended, and revert, by contraction, to the octagon form. But in the Stinger *alone* have I *seen* the germs remaining, for some time after exclusion, in the same *mulberry* clusters in which they had occupied the sinuses of the plicate ovary. I have this year, 1846, collected the ova of a very different Medusa. These were, at first sight, pyriform like the others; but afterwards proved to be (what I have never *discovered* in any other species) much compressed, and, from a *swinging* fashion in swimming, were often seen edgeways, and looked like little *Planariæ*. They are now as decided *Hydræ* as the others, and can *just* be discerned as such with the naked eye. I have only seen the ova of two other Pulmogrades; both *very* minute and of the *Moorish-arch* form: *all* agree in being pyriform, locomotive (ciliomotive?) and *peristaltic*, which last habit I conceive to be the means of *steering*.

Embryogeny of Ciliogrades.—Of the true *Beröe* I can say very little: I am *pretty* sure I have had their ova two or three times, looking very like those of *Cydippe pileus*, but never succeeded in *hatching* them. However small the Beröe, and I sometimes meet with them *as small as a pin's head*, it differs in no respect but size from the adult, having eight ciliamina (ciliary arches). But *C. pileus* (a much commoner animal at Birkenhead) has afforded me repeated opportunities of watching the whole process, though with many interruptions. One first sees a little darkish but reflecting spherule in the centre of a proportionably *very* large, transparent, and scarcely visible pellicle: it very soon looks *granular* like boiled sago *within* and *without*; then shows a few obscure cilia—enlarges at one end, and becomes accurately *acorn-shaped*, with *only four* arches of cilia, which are, towards the base (or cup of the acorn), *immensely large* in proportion, much-curved, and move *very* slowly in general. The mouth is *large*, and apparently *linear* instead of the convolvulus form of the adult, and seems to take in *certain granular bodies which float within the pellicle*. The two *very* long trains are extended even in ovo, where there is *ample* room for "little master" to play about (it is a *nursery* rather than a *shell*); the trains are gathered into a *knotty bunch* instead of a cork-screw circus, *appear* to have *no* side filaments, and *certainly* have no internal sheath for their reception. After escaping from the shell, they exhibit greater activity, with startling alternations of *extreme, crawling* slowness during the extension of the trains, and the most fantastic capers after *suddenly* retracting the latter. These creatures are just visible to the naked eye, and as they are not easy to keep alive, I have never seen the next step of their metamorphosis, but have often met with Cydippes of the size of *hempseed* in the *normal* form, with convolvulus mouths, eight ciliamina, *fringed* trains retractile into *pockets*, and all the airs and graces of the full-grown individuals.

On the Quasi-osseous System of Acalephæ. *By* JOHN PRICE, *M.A.*

The author described minutely the tessellated structure of the polygonal central patch in the great brown Stinger (*Medusa capillata?*), and noticed the degree of analogy which this structure may be thought to offer to the osseous arrangements in higher grades of life. He offered suggestions as to the respiratory and nutritious processes in Rhizostoma, and presented some ground for doubt regarding the true nature of the supposed eyes of Acalephæ.

The author appended notices regarding *Beröe* (*ovata?*), especially its internal contractions, and recommended the examination of the structure of this singular Acaleph, by microscopic investigation of the *process of natural decay*, "which in Acalephæ is apt to take place symmetrically, so that the anatomy is laid bare bit by bit, whilst vitality remains almost unimpaired in the very last shred of the frame."

[In the letter to Professor Owen which accompanied these communications, other interesting remarks and queries occur.]

On the Cultivation of Silk in England. *By* Mrs. WHITBY.

A letter was received from Mrs. Whitby, of Newlands near Lymington, wherein she stated to the Association the encouraging result of an experiment,

ten years ago on her own estate; and she exhibited specimens of raw and manufactured silk with full details. She began by planting various sorts of mulberry-trees, of which she finds the dwarf Philippine is by far the best, as producing more leaf, and (from the facility with which its cuttings are struck) more easily propagated than any other. Of the various races of the silk-worm, she finds that by procuring the eggs of the large Italian sort, of four changes, she obtains as great a proportion, and as good a quality of silk, as they do in Italy or France. The testimony of several eminent manufacturers in London, Manchester and Coventry attests this; and Mrs. Whitby has had the satisfaction of presenting twenty yards of rich and brilliant damask, manufactured from silk grown at Newlands, to Her Majesty Queen Victoria, who was graciously pleased to accept of this indication of a new source of riches in her dominions.

After making every allowance for occasional unfavourable seasons, and labour, machinery, outlay of money, &c., it will be found that land laid out for furnishing food for this valuable caterpillar, will yield at least £20 per annum.

The computation is briefly as follows:—one oz. of eggs produce 40,000 worms, which require 1400lbs. of leaves; deducting 25 per cent. for accidents, there will remain 30,000 cocoons weighing 75 lbs., which at 10 lbs. per cwt. of silk, will yield 7½ lbs. of the best raw silk (besides refuse), equal, at 23*s.* per lb., to 8*l.* 12*s.* 6*d.* One acre of land bearing 1225 plants of six or eight years' growth, yields 4900 lbs. of leaves, and will consequently feed 3½oz. of eggs, which at 8*l.* 12*s.* 6*d.* nett per oz. as above stated, yields 30*l.* 3*s.* 9*d.*, and deducting 33 per cent. for labour, machinery, &c., 10*l.*, there will remain a final profit per acre on 3½oz. of eggs, 20*l.*

On the Structure of Cristatella mucedo. *By* Prof. Allman, *M.R.I.A.*

In this beautiful little Bryozoon, added to the Irish Fauna by Prof. Allman, several interesting peculiarities of structure were detailed. Of these the author considered one of the most important to be the detection of a small roundish body, situated at the upper end of the pharynx, and which he believed to be a nervous ganglion. The author also dwelt upon the existence of a delicate calyciform membrane which unites the bases of the tentaculæ, and is of very general occurrence among the freshwater Bryozoa. This structure he considered peculiarly interesting, as it tended with other facts to homologize the tentacular system of the Bryozoa with the branchial sac of the true Ascidiæ. Several peculiarities in the digestive and muscular systems were also alluded to, the muscular fibre being shown to be obscurely striated, and to exhibit a tendency to break itself into discs. The ova in their young state are inclosed in a ciliated membrane, and the hooked spines with which, in their more mature condition, they are furnished, are developed within the ciliated investment, being of subsequent growth, but yet fully formed previously to the ova quitting the parent. The facts detailed in the present communication were assumed by the author as affording much additional evidence in favour of the molluscan nature of the Bryozoa.

Observations on the true Nature of the Tendril in the Cucumber. *By* T. Bell Salter, *M.D., F.L.S.*

While it is now admitted that the tendril is a modification of some essential part of the plant, it is in most plants sufficiently obvious what organ is so altered, as for instance, the leaf or petiole in the leguminose plants, the peduncle in Passiflora, and the primary axis of the plant in the vine; in this family it is not so obvious. In the monstrous state of a cucumber plant now shown, where all the parts appear in a more elementary form than in its natural state, we have this question satisfactorily solved. While the female flower is resolved into an aggregation of thick adherent leaves, and the staminate flowers into an aggregation of leaves not adherent, we see the tendril as a simple slender leaf, and not a branch bearing any aggregation of leaves, as it would be were it any modification of a branch, or any part of the inflorescence. It would appear from this that the tendril in this genus and family represents the leaf, while the developed leaf next to it is the first leaf of a sessile axillary branch.

On an undescribed Alga allied to Coleochæte scutata. *By* Professor ALLMAN.

This paper contained a description of an alga discovered in certain subalpine streams in Ireland. It presents the appearance of small perceptibly elevated discs of a dark green colour, varying in size from about half a line to three lines in diameter, and attached to the upper surface of stones in the most rapid part of the current. When several plants grow upon the same stone they often become confluent, and form patches of indefinite figure and extent. Each plant is of a firm, almost cartilaginous consistence, and an ordinary lens shows it to be furnished with a margin divided into rounded lobes. Under a higher magnifying power the structure is found to consist of numerous disc-shaped laminæ, placed one over the other with an imbricated arrangement, the margin of each projecting beyond that of the superposed lamina. The lowest lamina is always the youngest, and each consists of many dichotomously branched series of nucleated cells, which radiate from a common centre, and are united at their edges into a continuous frond. In no specimens, though examined at various seasons and at different stages of development, were the sheathed setæ of *Coleochæte* detected. From the only described species of *Coleochæte*, therefore, the present plant differs in its lobed outline, in its imbricated structure, in its firm consistence, in its large size, in the absence of setæ, and in its habitat. The author believes it to be generically distinct from all hitherto described forms, though standing near to *Coleochæte* or *Phyllactidium*; he proposes for it the name of *Sorodiscus rivularis*.

On the means of obviating the ravages of the Potato Disease, by raising fully-grown healthy Potatoes from seed in one season. By W. HOGAN, *M.R.I.A.*

The method was discovered by M. Zander of Boitzenburg, who has practised it for six years with the greatest success*.

The following extracts are from M. Zander's published letter:—

"I first raised potatoes from seed six years ago. I sowed an eighth of an ounce, and obtained nearly seven sacks of fully-grown, perfectly sound potatoes, although in the same year almost all the potatoes in my neighbourhood were affected by pock-mark and dry-rot. I have regularly raised potatoes from seed ever since, and they have remained sound during the whole time, and last year (1845), when the disease had spread over all Europe, and attained the greatest virulence in this neighbourhood, those potatoes which I had previously raised from seed, as well as those of the preceding year, continued perfectly exempt from disease. I have given potatoes raised from seed to my friends and acquaintances, and those have also remained perfectly free from the universally prevailing disease. From an ounce of seed you may raise upwards of fifty sacks of potatoes: the smallest crop I ever had from half an ounce was twenty-four sacks.

"The seed is saved in the following manner:—the berries should be gathered in autumn, before the frost sets in, and be preserved in a dry place, where frost cannot reach them, until the end of January, when the berries should be broken by the hand and placed in a tub or other vessel for six or eight days to ferment; water should then be thrown on them and well-stirred in order to separate the pulp and husks from the seed, which should then be dried and cleaned, and kept in a warm dry place until the middle of March.

"In the middle of March or beginning of April, the seed should be thinly sown in a hot-bed, and by the middle of May there will be fine healthy plants which may be put out into the field; care should be taken to put them out before they form tubers, and the seed-bed should be kept moderately moist while they remain in it. They should be planted out after rain, and be put at about the same distance from one another as potatoes generally stand in the field."

The foregoing extracts contain two most important statements:—one, that it is possible to raise an abundance of fully-grown potatoes from seed in one season; and the other, that such potatoes will resist and escape the generally prevailing disease, for six years at least. Mr. Hogan then entered into a statement of his own observations on this mode of cultivation in two widely-separated localities in

* In a report made by M. Zander, he states that his plan was equally succes
crop of 1846.

which perfectly confirmed M. Zander's statement as to the first point, but suggested that many experiments must be made in various places and under various circumstances, before it can be certainly said, that potatoes raised in this way would resist and escape the disease, though he expressed his hope and expectation that they would.

On proposed Substitutes for the Potato.
By T. D. Morriss-Stirling, *F.R.S.E.*

The Jerusalem artichoke, Scorzonera, and plants containing starch in their roots, were proposed; and as a means of improving the potato plant itself, it was suggested that hybrid plants should be produced between the *Solanum tuberosum* and some hardy species of Solanum, such as the *Solanum nigrum*.

Dr. Lankester exhibited the woody fibres of the *Lavatera arborea* which had been sent to the Section by Capt. Peterson through Capt. Ibbetson; with the suggestion that it might be of use in the arts and manufactures of the country. This plant grows abundantly on some spots in the Isle of Wight, and could probably be easily cultivated.

On the Development of Cells. *By* A. Henfrey, *F.L.S.*

The author believed that in all cases these were developed from a folding-in of the primordial utricle. He was inclined to regard the evidence hitherto produced of the production of cells from cytoblasts as inconclusive. He did not think that the cytoblasts were the efficient cause of the development of the new cells; but that their presence in certain cases of multiplication of cells by division had led Muller, Schleiden and others to a misconception of their function. The cytoblast is usually present at an early period of cell-life and of the full size; and cell-division takes place, or commences, at an epoch when the cytoblast completely fills that portion of the primordial utricle which is about to form a new cell. When the utricle expands to form a cell, the cytoblast remains either on its walls or free in the cavity. We have here an appearance simulating the development of membranes from a cytoblast as described by Schleiden; and it is probable that these appearances have given rise to Schleiden's theory.

Comparison of the Periods of the Flowering of Plants in the early Spring of 1846, *in the Botanic Garden of Belfast, and the Jardin des Plantes at Paris.* *By* W. Thompson*.

The comparison showed that the same species flowered much earlier at Belfast than at Paris; though at the latter locality the spring of 1846 was the earliest of the last forty years. It was suggested that returns of this kind from the Botanic Gardens of the United Kingdom, and these again compared with similar catalogues from the public gardens on the continent, would possess much interest in various points of view.

Notes on additions to the Flora of Ireland. *By* W. Thompson.

A few species of phænogamic and cryptogamic plants were noticed as additions to the flora of Ireland, and specimens exhibited. The phænogamic species were chiefly collected by Mr. D. Orr, foreman in the Belfast Botanic Garden.

Notice of the Shea Butter-Tree growing in Africa. *By* J. F. Duncan.

This tree was first discovered by Mungo Park. It produces from its seeds a quantity of oily matter, which is used by the natives as butter. It is as hard as tallow, and may be used for making it. Some candles made of the oily secretion

* Published in detail in ' ' History for April 1847.

were exhibited to the Section and burnt; where they gave as good a light as those from any other oleaginous compound used for this purpose.

Mr. J. F. Duncan forwarded a fruit in many respects resembling an orange which he had observed to grow abundantly in Africa. When pulled from the tree in a ripe state the interior substance is about the consistence of an orange, and is considered superior to anything manufactured in England, as soap.

On the Foliage and Inflorescence of the genera Phyllanthus and Xylophylla. *By* B. CLARKE, *F.L.S.*

The leafy appendages from which the flowers in most of the species of these genera spring have been described by authors in general, up to the present time, as branches. The author, having examined their structure and relations closely, has come to the conclusion that they are in almost all cases true leaves. Several species of the genera Phyllanthus and Xylophylla were described, and the author's views of their structure explained by drawings. In conclusion, he suggested whether the additional leaf-buds which are sometimes seen in the axils of leaves do not originate from the base of the petiole. Such buds occur in the genus Rubus; in some species of which the additional bud is developed beneath the axillary bud instead of on one side of it.

The following letter from the Hon. F. Strangways was communicated by Sir R. I. Murchison, G.S.St.S.:—In the neighbourhood of Alexandersbad, near Wunsiedel, a few miles south of the road from Bayreuth to Eger, in the Fichtelgebirge, is a mountain called now the Louisenberg—formerly the Luchsberg—which is much visited by strangers on account of some of its natural peculiarities. It appears not to consist of any mass of rock *in situ*, but to be an enormous heap of disconnected, but rounded fragments of granite, thrown confusedly upon one another, leaving arches and passages and grottoes of various sizes wherever the interstices have not been filled up with smaller pieces, together with granitic gravel. The whole is so overgrown with wood, that, except where paths have been made, it is difficult to penetrate. The rounding of the blocks seems to be rather the effect of disintegration than of water. One of the caverns or chambers, formed by a single flat table of granite resting horizontally, as a roof, upon other masses, is a tolerably exact circle of nearly sixty feet English in diameter. Many that penetrate deeper into the mountain or mass of rocks are mere crevices; but they present a remarkable phænomenon, which is not observable in the more open ones. This phænomenon consists in a pale but beautiful greenish-yellow phosphorescent light, which, as the observer proceeds into the cave, becomes stronger and stronger, till it can be compared only to that of hundreds of glowworms lying close together on the ground; and it is singular that the light, however strong it may be, does not assume the appearance of a sheet, but always seems to lie in spots, though close together. On taking up some of the mould upon which this phosphorescence appears to rest and bringing it to daylight, its own light, as might be expected, is overcome, and disappears; nothing being seen in the hand but the black earth, a little sand, some minute whitish cryptogamic powder (?) and a few fronds of a very small filmy moss of a pale, transparent green colour. On taking the mould back into the darkness, the phosphorescence re-appears, but so much dimmed that it should seem as if the slightest disturbance had a tendency to dissipate it, and that it required time and repose to form or collect it anew. The traditions of the country, or rather the superstitions, have long pointed out this mountain both as the repository of gold and precious stones, and as the abode of evil spirits, or Kobolds, who amuse themselves by tantalizing credulous mortals with the view of gems and riches without end, which, when touched, are turned into dross or vanish from the sight. The explanation given by this phænomenon to such a belief, current among a simple and imaginative people, is evident. The original name of the mountain itself, Luchsberg, *i.e.* Lynxberg, is somewhat expressive of this peculiarity.

MEDICAL SCIENCE.

On the Physiology of the Encephalon. *By* W. B. CARPENTER, *M.D., F.R.S.*

THE object of this communication was to bring under consideration the inferences to which we are led by the study of Comparative Anatomy, in regard to the functions of different parts of the human encephalon. He first pointed out that our comparisons need not be restricted to vertebrated animals, since the ganglionic centres of invertebrata may be shown to be analogous with certain portions of the cerebro-spinal system of the vertebrata. He stated it to be a universal fact, that all organs of special sense have distinct ganglionic centres, which must be regarded as the instruments of their respective sensations and as the sources of motions directly connected with those sensations; and that the whole cephalic mass of invertebrated animals was composed of a collection of such ganglia, without any vestige (except in the highest) of cerebrum or cerebellum. These organs make their first appearance in fishes; and bear at first but a small proportion to the chain of sensory ganglia, which forms the anterior termination of the spinal cord. In fishes we find distinct olfactive, optic and auditory nervous ganglia, together with thalami optici and corpora striata, the degree of development of which has no reference to that of the cerebrum; in fact, the bodies usually called the cerebral lobes of fishes are (except in the sharks, &c., which have vestiges of cerebral hemispheres) almost entirely composed of the homologues of the corpora striata. Hence Dr. Carpenter considered that these bodies, instead of being appendages to the cerebrum, really belong to the group of sensorial ganglia, and are to be regarded as together making up the ganglionic centres of common or tactile sensation, and of the movements prompted or directed by it. This chain of ganglia, although comparatively small in man, with reference to the bulk of the cerebral hemispheres, still exists in him, and must be regarded as the instrument of the same operations as those to which it ministers in the lower animals. Arguing from actions in the latter, and analogous phænomena in man in health and in disease, the author attributes to the sensory ganglia the formation of sensations, and the origination of respondent movements, which may be distinguished as *consensual*. To this category the purely instinctive actions of the lower animals, which seem executed without any *idea* of purpose, and in simple respondence to the promptings of sensation, appear referrible; together with a variety of actions in man, such as that of yawning, from the sight or sound of the act in another. Dr. Carpenter hence endeavoured to show that we must regard the cerebrum as the instrument of the formation of ideas, of the memory of ideas and sensations, and of the intellectual processes founded upon them, which terminate in an act of the will; and he pointed out that *ideas* may produce the same effect on muscular movement as sensations themselves, as when the suggestion of the idea of yawning induces the action. He also showed how the anatomical connexions of the cerebrum with the sensory ganglia would cause its communicating fibres to exert an influence on the latter, corresponding with that which is effected by the sensations directly received from the organs of sense. With respect to the *emotions*, he endeavoured to show that they may be regarded as compound states resulting from the simple feelings of pleasure and pain associated with certain ideas, or classes of ideas: the feelings of pleasure or pain he would locate, with the sensations which commonly excite them, in the sensorial ganglia; whilst the formation of the ideas, which are essential parts of the emotions and propensities, is clearly a cerebral operation: and he showed, in conclusion, how this view of the functions of the principal parts of the encephalon harmonizes with the known duplex action of the emotions,—first in producing involuntary movements, and secondly in stimulating and influencing the reasoning processes.

On the Relations of Sensation to the higher Mental Processes. *By* R. FOWLER, *M.D., F.R.S.*

The author observed that *man*, when viewed as a whole, should be considered as consisting of a body, constituting the instrument of the mind, as the telescope is of the eye, *adjustible* but not *adjusted* [illegible]ions are perceived through the

medium of the *muscular sense*, as the images reflected, or refracted in telescopes are the signs of external objects to the eye. Animals have adjustments ready-made: man has to learn his. To see and to touch, as an artist, or even in the common usages of life, a man just couched is as an infant; till he can adjust he sees, as we do with an unadjusted telescope, merely a vague light. This gives rise to *search*. To *see* with intelligence, we must *look*, that is, *exert* the combined adjustments: this constitutes an appreciable distinction between *sensation* and *perception*. The unadjusted impressions pass the mind as vague trains of thought, linked and associated sequences, the machinery of reveries and dreams. That searching to obtain well-defined perceptions is effected by adjustments, attention to our own *working observation* will afford abundant proof; but a more protracted attention is necessary to prove, and to convince a man, that his *memory* and *powers of conception* equally depend on the mind's perception of *a reiteration of the adjustments of sensation*. But that this is so we have proof, in the *corporeal* actions induced by conception being like those produced by sensation in the presence of the objects. Thus conception of savoury food excites secretion in the salivary glands—the conception of an insult excites the feelings and gestures of anger, &c. In *the power* of forming and giving fixity of tenure to conceptions men differ widely. It is to this power Dr. Johnson alludes, when, in his Tour to the Hebrides, he says, that whatever can make the past, the distant and the future prevail over the present, raises us in the scale of thinking beings. Now Dr. Darwin and Sir David Brewster have shown that these conceptions are effected by adjustments of the body; in other words, that the "mind's eye" is, in fact, the body's eye. To have vivid conceptions disposable by our volition, forms the orator, the poet, the sculptor and the painter. After numerous illustrations of this faculty and allusions to it by the poets, the author stated that these sensations, perceptions and conceptions do not exist in an insulated state; the adjustments by which they are affected are so linked and associated by retransmissions through the brain to the other organs of sense, that they reciprocally call up each other. This *linked association of adjustments* he took to be the machinery by which the *association of our ideas* is effected, and that *the propensity of our structure to these functional adjustments* constituted all we had of *ideas* which had been denominated *innate*; and he considered that this reciprocating perception from different sources of sensation (as the eye and ear) gave birth to the ideal theory of "species, images of forms and colour of things without their matter," of the old metaphysicians. In conclusion, the author contended that Mr. Hume's opinion on the non-existence of the idea of power, and of cause and effect (except as antecedent and consequent), and the arguments and facts adduced against that opinion, receive an elucidation from the consideration of the modes of action of the muscular sense, but of which neither Mr. Hume nor his critics could at that time have been apprised, as the discovery had not been completed.

Yet these impressions (our guides in all corporeal exertions) belong alike to men and all inferior animals, and must have been at all times, and in all places where muscular exertions have occurred. Yet such is the law of sensation, that the mind passes this muscular feeling unnoticed, and attends solely to his perception of the object by which the sensation was excited. Thus the attention of the seaman who heaves the lead is directed only to the contact of the lead when it touches the bottom. Every boy who throws a stone, every horse on its approach to a leap, estimates its power by these feelings, although thinking at the time only of the distant *object of its aim*. I think any man capable of making his sensations the subjects of his thoughts, may satisfy himself that our ideas of cause and power have their source in these and like evanescent muscular feelings or impressions.

Is it not, too, from similar feelings of muscular power, recognised from day to day to be the same which we have felt from our earlier years, that we are assured of the continuance of our personal identity?

On the Cause of the Blood's Circulation through the Liver.

By CHARLES SEARLE, *M.D.*

After alluding to the powers which circulate the blood in the system generally, the author declared it to be still a problem by what combined forces the portal circula-

tion was carried on in the liver,—one cause of the general circulation being apparently absent, namely, the oxygenation of the blood in the arterial system, in the portal system the blood being deemed wholly venous. The solution of the problem depended, he thought, on the fact that the stomach and bowels were (like the cutaneous) a respiratory surface, by which the portal blood becomes oxygenated to the necessary degree. In support of this view he adduced the experiments of Majendie, who found eleven per cent. of oxygen in the stomach of criminals examined after decapitation, and carbonic acid and nitrogen in the intestines; the source of this oxygen he believes to be the air swallowed with the food and saliva, and in combination with cold water. This oxygen he believes to be absorbed by the veins and lacteals, and communicated as a source of power to the portal vessels. He deemed the absorbing power of the gastric and mesenteric veins to be increased by the diminution of the quantity of blood in the vessels by the secretion of bile. In conclusion, he thought the ruminant animals required an additional supply of oxygen to maintain the respiratory function over their large gastro-intestinal surface, and that this was supplied from their peculiar function of rumination.

On some Diseases resulting from the immoderate Use of Tobacco. *By* T. Laycock, *M.D.*

The diseased action from the continuous and immoderate use of this poisonous substance was observed to pervade the mucous membranes of the digestive and respiratory systems, producing congestive inflammation of the fauces and stomach, and of the nares, frontal sinuses, larynx, and bronchial lining of the lungs. Gastritis with the symptoms of aggravated indigestion and hæmoptöe were among the worst results of these affections; but it was found in many cases to produce disease of the circulating organs and of the nervous system—weakening the force and regularity of the heart's action, and diminishing the intellectual and moral powers. In conclusion, Dr. Laycock read a report from Dr. Wright confirming his own observations, and containing experiments demonstrating the physiological action of the drug on animals.

Diagrams showing the Mortality of Diarrhœa concurrently with progressive increase of temperature in London. *By* T. Laycock, *M.D.*

The lines representing temperature and mortality were seen to be persistently, and even minutely regular; not coincident in point of time, but those indicating the mortality following those of temperature by about a week's interval. The tables extended over five years, and the uniformity of elevation and depression continued throughout.

On a peculiar form of Ulceration of the Cervix Uteri. *By* Dr. H. Bennet.

STATISTICS.

Statistics of Civil Justice in India for four years, from 1841 *to* 1844, *both inclusive.* *By* Lieut.-Colonel Sykes, *F.R.S.*

The present returns are supplementary to those published by the Statistical Society of London, and are brought forward by the author as well to test the continued working of the system of administration, as to afford data for determining the effect of the recent politic efforts to improve the intellectual standard of the native administrators, by introducing into their body natives who have passed certain prescribed examinations at the colleges and schools established by the East India Company in their territories in India. The returns [illegible] satisfactory. Under the four governments of India,—Beng[illegible] v, the whole of the courts, both Euro-

pean and native, with few exceptions, appear to have got through the current business of each year; and to a greater or less extent to have diminished the arrears of former years.

The administration by natives appears to have worked quite as well as before; from ninety-seven to ninety-nine per cent. of the whole civil business having been performed by them; and sufficiently well performed, if the amount of appeals, and number of reversals of decisions, be the standards by which to judge. A decided improvement has taken place in the shortening the average duration of suits in all the courts under the Bengal and Agra governments; in the highest court of appeal, (corresponding to Chancery) from one year seven months and eight days in 1841, to one year and one month in 1844. The Zillah and city judges (European) shortened the time of their average decisions from ten months and eleven days in 1841, to seven months and seven days in 1844; the principal Sudder Ameens from seven months and ten days, to five months and twenty-two days; the Sudder Ameens from eleven months and fourteen days, to five months and five days; and the Moonsiffs from five months and nineteen days, to four months and fourteen days, from 1841 to 1844 respectively; the last three descriptions of judges being natives. The Agra judges were a still shorter average time in their decisions than those of Bengal,—the Supreme Appellate Court reducing its time from seven months and thirteen and a half days, to six months and eighteen days; the European Zillah judges from seven months and three days, to four months and sixteen days; the principal Sudder Ameens from three months and eleven days, to three months and seven days; and the Moonsiffs from three months and one day, to two months and twenty-one days. The Sudder Ameens had slightly increased their former average time.

The value of the litigated property before the tribunals in Bengal, varied from 7,845,178*l.* in 1841, to 3,006,154*l.* in 1844; before those of Agra, for the same periods, from 1,637,941*l.* to 1,442,861*l.*

Colonel Sykes observes, that an opinion obtains in England, and even in India, that the land-tax is oppressive to the cultivators or farmers; but under the Bombay government for the years 1842, 1843, and 1844, the only farmers or cultivators in jail at the instance of government for arrears of land-tax were nine, five, and two only for the respective years; and as this was out of a population of between six and seven millions of souls, it cannot be believed that the land-tax is of the oppressive character represented.

Statistics of the Criminal Courts of India. *By* Lieut.-Colonel Sykes, *F.R.S.*

The author submitted detailed tables of the operation of the various criminal courts under the four governments of Bengal, Agra, Madras, and Bombay. The want of a common form for the returns from the several courts under the respective governments occasioned discrepancies in the amount of the information supplied; a drawback upon the utility of the returns which can be easily remedied. In the Bengal courts, out of 322,394 prisoners tried in the four years, from 1841 to 1844, both inclusive, 112 offenders were condemned to death, being only 0·034 per cent. of the whole offenders, or one in 2878 criminals. In the Madras courts 271,842 offenders were tried during the four half-years, commencing with the second half of 1842 and ending with the first half of 1844, both inclusive; of this number eighty-four were condemned to death, or 0·031 per cent., or one in 3236 criminals; a singular approximation to the proportions under Bengal. In the Bombay courts, in the years 1843 and 1844, there were tried 113,080 offenders, and of this number forty were condemned to death; being 0·035 per cent., or one in 2827 criminals; a still closer approximation to the Bengal proportions than the Madras returns gave.

The criminal courts of Bengal, Agra and Bombay, permit of appeals against their sentences to the Nizamut or Foujdary Adawlut, the supreme criminal court; and the importance of this privilege is manifested by the fact, that the Nizamut Adawlut of Bombay, in 1843, annulled ninety sentences and mitigated eighty-nine others out of 1021 appealed. Important modifications or revocations of sentences appear also to have taken place under the Agra government. The Bengal returns do not show the decisions in appeals; and, under the Madras government, the returns do not indicate that appeals are permitted.

Under all the governments in India, transportation for life in lieu of imprisonmer

for life had been substituted, or was in progress of substitution; and very lengthened imprisonments were discouraged.

Criminal jurisdiction in minor cases appears to be exercised by the superior native judges under all the governments.

The proportional sentences of death in India contrast very favourably with similar sentences in England and Wales, in the corresponding years. In England and Wales in the year

1841.....	Prisoners	27,760	Sentences of death.....	80
1842.....	ditto	31,309	ditto.....	57
1843.....	ditto	29,591	ditto.....	97
1844.....	ditto	26,542	ditto.....	57
	Total	115,202	Total.....	297

which gives a per-centage of 0·258, or one sentence of death to every 388 prisoners; the proportion in Bengal being one in 2878. The committals to the population in England and Wales, in 1841, were one to 619 souls; and in Bengal, in the same year, one to 620 souls.

Statistics of the Government Charitable Dispensaries of India. *By* Lieut.-Colonel Sykes, *F.R.S.*

The chief object of the author was to show the practical good resulting from the education afforded in medicine and surgery to young natives of India, principally in the Medical College of Calcutta. Young natives, having passed certain prescribed examinations, were appointed to the charge of government charitable dispensaries benevolently established by the government of India in Bengal and the north-west provinces. The dispensaries, seventeen in number, were respectively in charge of the native sub-assistant surgeons; but under the control of the civil surgeon of the station, or that of the superintending surgeon of the district. Both the superintendant and the native sub-assistant surgeons were directed to report half-yearly, for the information of government, to the medical board at Calcutta. These reports were made in English, and several of the reports of the natives were not distinguishable from those of the highly-educated European surgeons, whether in grammatical construction, technical phraseology, perspicuity in expression, or rational observation. Some of the reports embraced the writer's views upon the drainage and sanatory condition of towns; the influence of intramural or proximate burial-grounds (Mahomedan) upon public health; the meteorology of the seasons, as influencing disease; the superstitions and prejudices of caste in the people, as debarring the people from deriving the full benefit of the dispensaries; upon the use of the dispensaries as schools of instruction;—these, and many other topics, are ably noticed in several of the reports. All the sub-assistant surgeons use the knife with dexterity and success, amputating limbs, cutting for the stone, couching for cataract, &c.; and some of them send drawings of the stones they extract; others report upon the introduction and use of new medicines (unknown to English pharmacy); and one of them (Ram Narraen Dofs, of Cawnpoor) gives a botanical description, and sends a drawing of a plant (a Convolvulus) producing a new medicine, a substitute for rhubarb; others give a chemical analysis of the new medicines they introduce, and sometimes re-analyse medicines with metallic bases used by the hakeems or physicians of the country. In all, 232 new medicines are brought to notice. The reports are accompanied by tabulated returns of the diseases treated, arranged under fifty-eight heads, with a column of 'alii morbi,' which, in spite of the fifty-eight diseases enumerated, is very comprehensive in its character. The returns from the majority of the dispensaries are for six half-years, and these Colonel Sykes has arranged, added up, and analysed. The results showed that the "House List" and the "Out Patient" practice embraced 267,456 cases, of which 168,871 were cured, 2417 died, and 96,768 ceased to attend, and the results were not known. Colonel Sykes treats in detail of local peculiarities in the development of diseases. He concludes his paper with the following observations:—"In conclusion, it has been contemptuously said, and is still said, that in case the Company's government in India were swept away, not a monument of its existence would remain to attest its fo— [illegible] power. No doubt the governments that have preceded [illegible] nt proofs of their existence. The early

Buddhist and Hindoo authorities have indeed left prodigious monuments of their wealth, of their power, of their perseverance, and of their religious enthusiasm, in their mighty cave-temples, and vast religious edifices. The Mahomedans, too, have studded the lands with their magnificent mausolea, testifying rather to their pride than their piety. And what have the British done? I say that we have raised greater and more lasting monuments than all these. One small extract from a report of a *native* sub-assistant surgeon shall justify my assertion. Chimman Loll, of Delhi, says—

'1*st August* 1841.—*One boy, about twelve years of age, who had been blind from cataract in both eyes from the age of two years, was operated on by couching, and restored to sight.*'

"The faculty given to a single *native* to perform the godlike office of restoring the blind of his countrymen to sight, is a more glorious monument than all the works of art that human pride or human ambition have ever burthened the earth with; but when we find scores of such individuals endued with such a faculty, and thousands, nay tens of thousands possibly, the recipients of the blessing they can confer; when we find the medical board of the Bengal government reporting to government on the 22d August 1843, 'We have every reason to believe that the benevolent intentions of government in founding these institutions (the dispensaries) have been fully realized; and we feel confident that future annual results will add to the intrinsic value of the dispensaries, which are so well adapted, by their internal œconomy, to obtain the confidence of the native inhabitants. Many have had their sight restored, others have been cured of hydrocele, and relieved when in the last stage of dropsy. Several also have derived effectual relief from the successful operations for stone in the bladder; a few have been saved from a miserable death by the amputation of diseased members; and large tumours have been removed. Such operations could not have been achieved by native practitioners without producing an impression on the minds of the most apathetic natives; and they must tend to spread far and wide the value of the government dispensaries.' Then, I say, and with a thorough conviction of the truth of my assertions, in case the seeds of knowledge we have thus sown fructify to a general and luxuriant harvest, that we shall have left a monument, compared with which those of Ashoca, Chandra Gupta and Shah Jehan, or of any other Indian potentate, will sink into insignificance, and their names shall fall on men's ears unheeded; while those of Lord Auckland, as projector, and of Goodeve and Mouatt and others as zealous promoters of scientific native medical education, shall remain embalmed in the memory of a grateful Indian posterity."

Colonel Sykes only cursorily noticed the charitable dispensaries under the Madras and Bombay governments, in consequence of the absence of detailed reports.

On the Medical Relief to the Parochial Poor of Scotland under the Old Poor Law. By Prof. ALISON, *M.D.*

It was stated that as the objections made by Dr. Chalmers and others to establishing a legal and adequate provision for the poor in Scotland did not apply to medical relief, the efficiency of that relief, under the old Scottish law, would be a fair test of the efficacy of the voluntary system of charity. An association of medical practitioners was formed at Edinburgh, in November 1845, to collect information on this subject. It appeared that in Edinburgh there was no provision for medical relief from the poor-funds, except for the indoor paupers in the charity workhouse. Previous to 1815 no assistance was given by any institution to the sick poor at home; and though since that period the duty had been gratuitously undertaken by the officers of several dispensaries, it had not been effectually or regularly performed. In the Canongate, the dispensary aid to the poor came to a sudden close in the midst of the late epidemic fever, in consequence of the death of one of the medical officers who had acted as treasurer. By the recent Act ten duly qualified and paid officers have been appointed to take charge of the sick paupers in the different districts; but Dr. Alison lamented that the provision had been abandoned which compelled the parishes to *com'* giving relief, as in Edinburgh the rich congregate at one extremity of the the poor at the other. In Glasgow relief has been given by paid medical a for some years. Returns were obtained from forty towns, exclusive of F and Glasgow;—from which it appeared that in sixteen of these towns

absolutely no *requited* medical relief, either from the public authorities or from voluntary subscriptions. In four, an occasional payment, never exceeding a few shillings, had been made on special occasions. In Campbeltown 10*l.* was allowed to the professional men during the epidemic fever. In Kirkintilloch a similar sum was given, but by a private individual. In Dundee during the same fever 5*l.* each was allowed to six dispensary surgeons. In some other places 2*l.* was given to a surgeon; and in others a small allowance was made for drugs. In anticipation of the new Poor Law, 10*l.* has been allowed annually for medical relief in Alloa. In Dunbar 6*l.* 6*s.*, but this includes the supply of drugs. In Dunfermline 20*l.* a year, not including drugs. In Greenock 25*l.* per annum has been paid to each of three district surgeons. In Kilmarnock 10*l.* each to three surgeons. In Wick 15*l.* is divided between two surgeons. In Dumfries 10*l.* to one surgeon. The unrequited medical labour is stated by twenty-five gentlemen, and ranges from 5*l.* to 220*l.* annually in value, giving an average of 40*l.* per annum. But this is not the only tax levied on the charitable feelings of medical men;—in ninety per cent. of the cases they had to furnish wine, food, &c. out of their own substance; and in thirty-three of the forty towns brought under review, no change has been made in this system. Passing over the returns of infirmaries and dispensaries supported by voluntary contributions as rather imperfect, we come to the medical relief in the rural districts. The number of returns made amounts to 325. Out of these, ninety-four have received some remuneration, but only thirty-nine annually. Of these thirty-nine, only thirteen have received sums above 5*l.*; twenty-six above 1*l.* and less than 5*l.*; and nine 1*l.* or under. Ten are paid by the bounty of private individuals; and of these one is paid 60*l.* by a nobleman, and another 40*l.* by a landed proprietor; both, however, have the charge of extensive districts, and as there is no fund on which they can draw for drugs or necessaries, there are large drawbacks to be made from the remuneration. Twenty-three have received gratuities for their services, chiefly during the prevalence of epidemics. In one case this gratuity amounted to 20*l.*, and in fourteen it was under 5*l.*; in two cases it was only three shillings. In one of these cases this three shillings was the only remuneration for twelve years' attendance on paupers averaging seventy constant and thirteen occasional patients: in the other, the three shillings was a remuneration for passing paupers of other parishes, and *nothing was allowed for twenty-one years of attendance on resident paupers*, averaging forty-four constant on the district roll. 211, or above sixty per cent., have never received any remuneration of any kind for their professional attendance on the parochial poor, or for the drugs which they have deemed it necessary to supply to them; and 208 add that they have had occasion to give wine, food, &c. from their own limited funds, and that they had occasion to defray all travelling expenses when they made distant visits. 136 have estimated the money value of the unrequited labour which they have bestowed on the parochial poor:—it amounts to 34,447*l.* annually, or an average of 253*l.* each. The complaints of inattention to sick paupers by the parochial authorities are very general; and when applications were made for the repayment of different outlays, they were almost invariably refused. It was stated that since the abstract presented to the British Association had been compiled, several additional returns had been obtained; but they in no degree tend to weaken the general impression likely to be produced by the preceding statement, and it was therefore deemed unnecessary to tabulate them.

Criminal and Miscellaneous Statistical Returns of the Manchester Police for the year 1845. *By* Wm. Neild.

Oxford University Statistics. By James Heywood, *F.R.S.*

A remarkable proof of the interest felt by eminent statesmen in the ancient universities has been recently afforded in the preparation of a memorial to the Vice-Chancellor and heads of houses at Oxford, for university extension. The memorialists were Oxonians, and several of them had previously obtained the highest academical honours of a double first class; but they had observed with regret the continuance of a system of large expenditure among the junior members of the university, and they

were on that account desirous that the educational advantages of Oxford should be rendered more accessible to the sons of parents with limited incomes. Their memorial in favour of the extension of the universities was signed by many eminent persons.

"Our university," observed these memorialists, "take up education where our schools leave it, yet no one can say that they have been strengthened or extended whether for clergy or laity, in proportion to the growing population of the country, its increasing empire, or deepening responsibilities."

The author gave the following table of the Oxford degree examination during the last six years, and commented on the general results:—

	Total number of Candidates.	Total number did not pass.	Total number passed.	Ordinary degrees.	Class Men.
1840.	424	117	307	210	97
1841.	399	140	259	154	105
1842.	426	136	290	188	102
1843.	409	111	298	200	98
1844.	409	132	277	198	79
1845.	398	120	278	194	84
	2465	756	1709	1144	565
Average per annum,	410	126	284	190	94

On the Duration of Life in the Members of the several Professions, founded on the Obituary Lists of the Annual Register. *By* Dr. GUY.

The following table exhibits the average of such as had attained or outlived the specified ages:—

Age.	Army.	Navy.	Clergy.	Law.	Physic.	Learned Professions.	Fine Arts.	Literature and Science, English.	Literature and Science, Foreign.	Trade and Commerce.	General average of England and Wales.	Nobility and Gentry.	Casper's Table of Medical Profession.
26 & upwards	65·27	67·63	68·81	66·20	65·36	67·70	64·42	66·49	62·78	68·11	....	....	58·00
31 —	67·07	68·40	69·49	68·14	67·31	68·86	65·96	67·55	66·72	68·74	....	....	59·27
41 —	68·97	70·01	71·82	70·20	70·23	71·24	68·21	69·15	68·42	71·01	....	....	63·82
51 —	71·58	72·62	74·04	72·78	72·95	73·62	71·15	72·10	71·44	72·32	75·64	74·00	68·21

If we confine our attention to the last line of the table, we shall see that the duration of life among the higher classes is shorter than that of the mass of the people of England, and of the provident members of the labouring class. In every age the navy possesses a very slight advantage over the army. The longevity of the clergy is superior to that of any of the other learned professions. The less favourable duration of medical life, in the tables published by Professor Casper of Berlin, is to be attributed to his having included a lower grade of the professions than those whose deaths are recorded in the Annual Register, probably such a class as the general body of medical practitioners in England. Both, however, show that medical men encounter the most danger at the early part of their professional career, and this is more apparent when the column of medical life is compared with that of law life. From his

own and other tables, Dr. Guy constructed the following summary of deaths at 51 and upwards:—

English males	75·64
Clergy	74·04
Gentry	74·00
Medical men	72·95
Lawyers	72·78
Navy	72·62
Trade and Commerce	72·32
English Literature and Science	72·10
Aristocracy	71·69
Army	71·58
Foreign Literature and Science	71·44
Fine Arts, &c.	71·15
Painters	70·96
Chemists	69·51
English Literature (according to Chambers)	69·14
Members of Royal Houses (males) ...	68·54
Kings of England	64·12

On the Mortality of Children. *By* Mr. WIGGLESWORTH.

It appeared that returns had been collected from 1987 families, in which the number of children was 10,076, giving an average of more than five in a family. The number of males was 5091, and of females 4985, which gives a proportion of 51 to 50. From these he constructed a table, showing the number out of which one child would die in one year, according to the experience of families.

Age.	Males and Females.	Males.	Females.	Age.	Males and Females.	Males.	Females.
1	9·62	8·34	11·40	12	196·05	193·20	199·70
2	16·88	17·01	16·75	13	279·38	356·20	231·37
3	32·38	31·00	33·63	14	195·88	271·16	154·82
4	47·14	49·32	65·25	15	153·70	165·33	144·18
5	65·51	67·21	3·94	16	200·14	123·63	480·67
6	90·38	108·85	77·59	17	171·67	176·57	167·37
7	95·83	83·21	112·48	18	190·25	158·43	242·00
8	143·14	120·52	174·80	19	162·15	166·67	158·28
9	137·80	124·53	153·56	20	158·00	101·67	327·00
10	281·63	369·67	228·80	21	121·43	138·67	108·50
11	155·93	160·16	152·00				

Taking the case of males and females conjointly, it will be seen that there is a gradual decrease from the 1st to the 8th year, and that there is an increase over the previous year in the 9th, 11th, 14th, 15th, 17th, 19th, 20th, and 21st years. In males these fluctuations take place in the 7th, 11th, 14th, 15th, 17th, 19th, and 21st years. In females there is a general decrease to the 8th year, and an increase in the 9th, 11th, 14th, 15th, 17th, and 21st years.—A table of diseases was then exhibited, from which it appeared that more males than females died of nervous diseases and from external causes; but that more females than males die of epidemic disease, and diseases of the respiratory organs. These tables, from family returns, were then compared with similar tables constructed from the statistics of the Foundling Hospital, and were found to agree very closely in their results.

A Review of the Mines and Mining Industry of Belgium. *By* R. VALPY.

It was stated that, as a coal-producing country, Belgium ranked the second in Europe. The ratio of the coal district to the total area is

		Acres.		Tons annually.
Great Britain ...	$\frac{1}{20}$, or	2,930,000	producing...	34,000,000
Belgium	$\frac{1}{78}$, or	335,000	„	4,500,000
France.....	$\frac{1}{110}$, or	630,000	„	3,783,000
Germanic Union		.....	.....	3,000,000

In 1838 the total number of coal-mines in Belgium was 307, with 470 pits in work and 172 in process of construction, employing 37,171 persons; being an increase of 8454, or twenty-eight per cent. on the number employed in 1829. The increase of the quantity of coal raised was not accurately ascertained, but it appeared to be about thirty-seven per cent. The average cost of production is 10*s.* 8*d.* per ton, and the average price 23*s.* 1*d.* for first quality, and 16*s.* 6½*d.* for the second quality of coal; the average rate of wages is 1*s.* 6$\frac{8}{10}$*d.* per day. The establishments for preparing other mineral productions for market in 1838 were—for iron, 221; copper, eight; zinc, seven; lead, two; the total number of furnaces was 139, of which forty-seven used coke and ninety-two charcoal. The total number of accidents from 1821 to 1840 was 1352, which occasioned severe hurts to 882, and deaths to 1710, making a total of 2592 sufferers.

On Plate Glass-making in England in 1846, *contrasted with what it was in* 1827. *By* H. HOWARD.

The writer furnished carefully all the materials for establishing this comparison. Amongst other results he stated, that in 1827 plate glass was sold for about 12*s.* average per foot, to the extent of about 5000 feet per week; in 1835, for from 8*s.* to 9*s.* per foot, to the extent of about 7000 feet; in 1844, for from 6*s.* to 7*s.* per foot, reaching about 23,000 feet; and in 1846, for from 5*s.* to 6*s.*,—about 40,000 feet per week. The sale is now about 45,000 feet weekly. He mentioned that, in 1829, a plate glass manufactory ceased operations because of the small profit realized when selling at 12*s.*; while, in 1846, a company, with a paid-up capital of 130,000*l.*, realized a net profit of 30,000*l.*, selling at from 5*s.* to 6*s.* Looking at this extraordinary increase, in spite of the severity of excise restrictions, the author asks, what would be the probable demand if the price were reduced to 4*s.* or 3*s.* 6*d.* per foot, which, free as the trade now is from excise interference, would yield an ample profit?

On the Statistics of Education in Glasgow in 1846. *By* A. LIDDELL.

This enumeration was collected by the Statistical Committee of the Sunday School Union of Glasgow. The returns show great disparity in the amount of instruction in the different districts into which the city has been divided. In Glasgow, instruction in the common branches of education may be had at the lowest rates; and when parents are so poor as to be unable to pay, it may be had gratis. The great amount of ignorance that prevails arises therefore from the apathy of parents; and in many cases, from their cupidity in sending their children to work at very tender years for the produce of their labour. To counteract this evil, various acts of parliament have been passed for the purpose of regulating the labour of children. The Factories Regulation Bill (Lord Ashley's) restricts the labour of youths in the factories named to about seven hours per day, thereby giving leisure for education and recreation; but it has been found that unless the service of youths can be got for as many working hours as that of an adult they cannot be profitably employed in these factories. No record exists by which we can learn the exact number of children employed in Glasgow prior to the passing of this Act, but there must have been several thousands; whereas, in March last, only 53 were so employed; and in Aberdeen, where formerly there were about 1000, there were at the same date only 45. The Act 8 and 9 Vict. c. 29, which came into operation in the beginning of this year, seems to be working more efficiently in promoting the education of the youths in the calico print works, to which class of factories this Act is restricted. It provides that the children shall have 150 hours' instruction every six months, between the hours of 8 in the morning and 6 in the evening. It is found that this enactment does not materially interfere with the œconomical working of this class of factories: consequently the children are still continued in employment; and, as far as can be ascertained from the few months' operation of the Act, they are making much more rapid progress than when receiving the same amount of instruction after work hours, which, being optional, was in many cases neglected altogether. In Glasgow, lack of education is much greater among the lower orders than in the country districts of Scotland; this in part arises from the wretchedly low pittance hitherto allowed to paupers; which compels many of them to resort to manufacturing towns for the purpose of obtaining

employment for their children. It has been ascertained, from the Statistics of the Night Asylum for the houseless and the police offices, that 46 per cent. of the paupers are not natives of Glasgow. An amendment of the Poor Law of Scotland passed the legislature last year, which, it is hoped, may in some respects remedy this evil. Under the authority of this Act, the parochial boards in the cities of Glasgow and Edinburgh have resolved on having industrial schools for the purpose of supporting and educating poor children. These schools have been for some time in operation in Aberdeen and Perth; and if generally adopted, may be expected to remedy the evil complained of in some degree.

Statistics of Crime in England and Wales, for the years 1842, 1843, *and* 1844. *By* F. G. P. Neison, *F.L.S.*

The first point to which attention was directed, was the necessity of viewing age as an element in every investigation into the amount and progress of crime. From an arrangement of the criminal returns for the above three years, in relation to population, it appeared that the tendency to crime among the male population, at different terms of life, will be found to vary from ·7702 per cent. to ·1694 per cent., or, in other words, the tendency to crime at one period of life is more than quadruple that at another. Similar results will be found for the female population, but with a lower specific intensity to crime. It was further shown, that in the counties and districts of England and Wales a different distribution of the population is found over the various terms of life. In Anglesea, Caermarthen, and Dorset, the proportion of the population alive in the quinquennial term of life, 20–25, is under 8 per cent. of the whole; while in Lancaster, Middlesex, and Monmouth, the proportion varies from 10 to upwards of 11 per cent.; and, since the tendency to crime at the same periods of life is more than quadruple that at other periods, it follows that, although the tendency to crime in those two groups were precisely the same at the respective terms of life, there would still, in reference to the whole population, appear to be an excess of crime in the three latter counties; therefore any method of investigation in which the element of age is omitted can never show the relative amount of crime. In illustration of this principle, it was shown that during the years 1842, 1843 and 1844, the proportion of criminals in England was 1 in every 336 of the male population; but if the population during those years had been under the same distribution in regard to age as in the year 1821, the proportion of criminals would have been only 1 in every 365 of the male population. Again, assuming the same tendency to crime at the respective terms of life to prevail, the differences in the distribution of the population would, for Glasgow, produce 1 criminal in every 304 of the male population; and in two districts of the metropolis the difference is so much as to give 1 in every 338 for Bethnal Green; while in St. George's, Hanover-Square, the ratio would be as high as 1 in 280:—showing a difference, or rather an error, in any such method of investigation of 21 per cent. The results for England and Wales establish the same truth. In Dorset, Anglesea, Cardigan, Caermarthen, Montgomery, Merioneth, and Pembroke, the ratio of crime would be one in every 360; but in Lancaster, Middlesex, Monmouth, and Glamorgan, the average would vary from 1 in 325 to 1 in 313 of the male population. It was thus made evident, that calculations on the progress and amount of crime in which the element of age is neglected cannot be relied on, as they would lead to the fallacious conclusion, that districts in which the same ratio of crime prevailed were at least 20 per cent. in excess of the average of the whole kingdom. A series of tables were brought forward, pointing to the existence of an interesting law in the development of crime. It was found that, in the male sex, from age 20, crime in each successive term of life decreases at the rate of 33¼ per cent., and in the female sex at the rate of 25 per cent.; so that if two tables were formed,—one in which the numbers resulting from such a law were given, and the other showing the actual number of criminals,—the one table, particularly in reference to the female sex, would be almost identical with the other. The paper went into an analysis of the various causes generally believed to increase or lessen the amount of crime in various districts; such as the prevalence of manufacturing, mining, and agricultural interests, the greater or less amount of wealth, and the degree of education. In the group [illegible]facturing and mining districts, it was found that the actual crir[illegible]he average of England and Wales by 2·3 per cent.; but in

the agricultural group of counties there is an excess of 5·9 per cent. of crime. Again, if the whole group of the manufacturing and mining counties be subdivided, it will be seen that in the northern mining districts crime is 52·1 per cent. below the average for the whole country; and in the cotton and woollen manufacturing districts crime is 7·0 per cent. under the average; but, on the other hand, in the districts where the silk and linen fabrics are manufactured there is an excess of 8·5 per cent. of crime, and in the hardware, pottery, and glass manufacturing districts the excess of crime is 33·5 per cent. above the average of England and Wales. It, however, appeared evident that there is something in the condition of the mining and manufacturing population having an influence in regulating the amount of crime,—one district showing an excess of 33·5 per cent., and another being under the average by, at least, 52 per cent. This led to an inquiry into the supposed increase of juvenile crime; and a series of tables were presented showing the relative amount of crime at the younger and at the more matured periods of life, by which it appeared that if the general result for any or all of the groups or districts, whether in connexion with an increase or decrease of crime, be compared with the corresponding feature at the juvenile ages, there will not be found a single instance in which the character of that result is so strongly confirmed by the facts for the younger ages as by those at the more advanced period. It follows that if any change be found to take place in the criminal calendar of a given district, such fluctuation will be promoted, not so much by juvenile crime, as by an increase or decrease among persons in mature life, when the conduct and dispositions of individuals come more under the influence of external circumstances. In order to obtain, as far as possible, districts in which the manufacturing or agricultural feature decidedly prevailed, a variety of combinations were made, in order to exclude foreign and disturbing elements. This was done to determine the legitimate influence of each particular condition of the people when unassociated, as far as may be, with other and different conditions; and the following is an abstract of the results obtained:—

District.	Difference per cent.	
	Increase.	Decrease.
Greatest manufacturing	18 2	
Greatest agricultural	6·0	
Manufacturing interest 33½ per cent. above the average...	10·8	
Agricultural interest, 50 per cent. above the average	4·2	
Manufacturing and agricultural interests nearly equal ...	4·5	
Greatest wealth	.....	8·8
Least wealth	.....	1·1

It is thus evident that so far no very marked feature has appeared to connect itself peculiarly with any individual group; and that therefore some further analysis is required in order to discover that element which is so powerfully concerned in producing the differences shown in some of the earlier combinations to which allusion has been made. In England and Wales, 33 per cent. of the males married under the Registration Act, signed their marriage registers by their *marks*, and taking this as an index to the state of education, a series of results is obtained. Taking the counties in which the proportion signing the marriage register with their marks exceeded the general average by at least 33⅓ per cent., and taking also the counties in which the ratio so signing their names is at least 25 per cent. under the general average, it is found that in the former, the amount of crime exceeds the proportion for the whole kingdom by 13·2 per cent., while in the latter group crime is at least 30·7 per cent. below the average for England and Wales. By some it may be held, that in the two groups now referred to, the difference may be owing to some other element than simply education. It may be said, however, that the difference may arise from the influence of some other element than education—such as the prevalence of peculiar manufactures subject to fluctuations in prosperity, to increased wealth, to difference of positions in society, and, in fact, to a variety of other causes not eliminated. To meet the force of this objection, each of the preceding districts or was divided into two sections, so that one section differed from the other in th

of education only which prevailed; a means being thus afforded of comparing two sections of a community similarly circumstanced in regard to manufactures, in regard to agriculture, or in regard to wealth as the case might be, in fact, differing only in regard to one important element of the inquiry, namely education; and hence the force of that element, if any, should appear. The following is a brief abstract of the results arrived at in this manner:—

Group.	Difference per cent. in crime.		Difference per cent. in favour of Education.
	Least Education.	Most Education.	
Greatest manufacturing	+48·4	+16·2	32·0
Greatest agricultural	+ 8·4	+ ·9	7·5
Manufacturing interest 33⅓ per cent. above the average	+23·2	− 7·2	30·4
Agricultural interest 50 per cent. above the average	+10·4	− 2·6	13·0
Manufacturing and agricultural interests equal	+15·8	− 9·3	25·1
Greatest wealth	+ 9·2	−29·4	38·6
Least wealth	+11·3	−13·5	24·8

In the above, the sign + signifies that the ratio of crime in that particular section is above the average for England and Wales; and the figures themselves point out the ratio per cent. The sign — is intended to indicate that the amount of crime is below the average. The last column gives the difference per cent. in the same district, which appears from dividing it into two sections, in the one of which there is the least degree of education, and in the other the highest. To the friends of education, the above results must be gratifying; showing, as they do, the immense advantages resulting from even the most elementary and mechanical acquirements towards education. There does not appear a single group in which there is not a striking difference in favour of education. In fact, a proper analysis of all the combined facts show, that following up the simple test here adopted, namely, the qualification of individuals writing their own names, the mere inability to do that much, is sufficient to account for, at least, one-third of the whole amount of crime in England and Wales.

On the Statistics of Sickness and Mortality in the City of York. *By* T. Laycock, *M.D.*

A Chart of the Railway lines of England, compared with a Diagram illustrating the principle of least mileage, was presented by Mr. Beaumont.

On the Annual Consumption of Coal and the probable duration of the Coal-Fields. *By* E. R. J. Knowles.

The author computed the annual consumption of coal at 38,000,000 tons as an average increasing with the population, and classified it under the following heads:—

Coal for household uses averaging 1·1 ton each person	22,000,000 tons.
Coal for manufacturing operations	12,500,000 ...
Coal for foreign exports	2,500,000 ...
Total...	37,000,000 tons.
Allowing for errors two and a half per cent. on above	925,000 ...
Thus making the total amount annually consumed	37,925,000 tons,

or nearly 38,000,000 tons for the present population, about 20,000,000. The extent of the coal-fields of England were taken at 5200 square miles (including the coal under the crop of the magnesian limestone, but not that under the new red sandstone), allowing an average of 20,000,000 tons to the square mile; and thence, after

making allowance for the coal worked out, and for the population being eventually doubled, it was deduced that the coal-fields of England contain an ample supply for at least 1500 years. Of the annual amount consumed for manufacturing operations, it was stated that the proportion of coal consumed for the purposes of steam-navigation (including the Royal Navy) most probably amounts to 1,075,000 tons, and for railway locomotion on 3000 miles of railway, to about 300,000 tons. It was remarked that 2840 miles in progress will probably consume about 275,000 tons of coal in addition to the above; to which a proper allowance for the lines, for which acts of parliament have recently been obtained, is to be added.

The above computations were offered only as an approximate calculation of an annual average with the present amount of population, many of the items being liable to great fluctuation, as in the case of coal consumed for the manufacture of iron: but it is only from an *average* that the probable duration of the coal-fields can be computed even approximately.

MECHANICAL SCIENCE.

On a new Method of Boring for Artesian Springs. By M. FAUVELLE *of Perpignan, in France.*

(A PAPER furnished by M. Arago to Mr. Vignolles, for the purpose of being communicated to the Association, M. Arago himself being prevented by illness from attending.)

The paper was an abridged translation of M. Fauvelle's own account, in which he says,—"In 1833, I was present at the boring of an artesian well at Rivesaltes; the water was found, and spouted up abundantly. They proceeded to the tubing, and for that purpose enlarged the bore-hole from the top downwards. I was struck by observing that it was no longer necessary to draw the boring tools to get rid of the material, and that the water, rising from the bottom, brought up with it, in a state of solution, all the soil which the enlarging tools detached from the sides. I immediately observed to my friend, M. Bassal, who was with me, 'This is a remarkable fact, and one very easy to imitate; if, through a hollow boring rod, water be sent down into the bore-hole as it is sunk, the water, in coming up again, must bring with it all the drilled particles.' On this principle I started to establish a new method of boring. The apparatus is composed of a hollow boring rod, formed of wrought iron tubes screwed end to end: the lower end of the hollow rod is armed with a perforating tool, suited to the character of the strata which have to be encountered. The diameter of the tool is larger than the diameter of the tubular rod, in order to form around it an annular space through which the water and the excavated material may rise up. The upper end of the hollow rod is connected with a force-pump by jointed or flexible tubes, which will follow the descending movement of the boring tube for an extent of some yards. This boring tube may be either worked by a rotatory movement with a turning handle, or by percussion with a jumper. The frame and tackle for lifting, lowering, and sustaining the boring tube, offer nothing particular. When the boring tube is to be worked the pump must be first put in motion. Through the interior of the tube a column of water is sent down to the bottom of the bore-holes, which water, rising in the annular space between the exterior of the hollow boring rod and the sides of the bore-hole, creates an ascending current which carries up the triturated soil: the boring tube is then worked like an ordinary boring rod; and as the material is acted upon by the tool at the lower end, it is immediately carried up to the top of the bore-hole by the ascending current of water. It is a consequence of this operation that the cuttings being constantly carried up by the water, there is no longer any occasion to draw up the boring tube to clear them away, making a very great saving of time. Another important and certainly no less advantage, is, that the boring tools never get clogged by the soil; they work c stantly (without meeting obstructions) through the strata to be penetrated getting rid at once of nine-tenths of the difficulties of boring. It addition, it be mentioned, that experience has shown there are no slips in any ground w

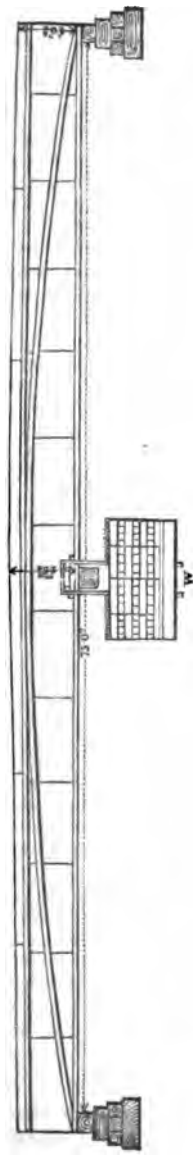
dinary boring-rods can penetrate; that the boring tube works at 100 yards in depth with as much facility as when only 10 yards down, and that from the very circumstance of its being a hollow rod, it presents more resistance to torsion than a solid rod of equal thickness and quite as much resistance to traction: these are the principal advantages of the new system of boring. Indeed these advantages have been fully confirmed by the borings which I have just completed at Perpignan. This boring was commenced on the 1st of July and was completed on the 23rd, by finding the artesian water at a depth of 170 mètres (560 English feet). If from these twenty-three days, each of ten hours' work, are deducted three Sundays and six lost days, there remain fourteen days or 140 hours of actual work; which is upwards of 1 mètre per hour, that is, ten times the work of an ordinary boring rod. In the method I have described, it will be perceived that the water is injected through the interior of the boring rod. Experience has taught me that when gravel, or stones of some size are likely to be met with, it is better to inject the water by the bore-hole, and let it rise through the boring tube. The additional velocity which may be thereby given to the water, and the greater accuracy of calibre of the tube, allow the free ascent of all substances which may be found at the bottom of the bore-hole, and which the former mode of working may not so readily accomplish. I have brought up by this latter way stones of 6 centimètres long and 3 thick (2¼ by 1¼ English inches). The idea of making the water remount through the interior of the boring tube suggests an easy mode of boring below a film (sheet) of flowing water: it would be sufficient to close the orifice of the bore-hole hermetically, still, however, so as to allow the boring tube to work, but yet so that the flowing water should be always forced down to the bottom of the bore-hole to find its way to a vent: it would thus draw up and carry away all the detritus. If, in addition to the above, we consider the possibility of making the hollow stem of the boring rod of wood, and of balancing it so that it would weigh no more than the water in which it has to move, the problem of boring to depths of 1000 mètres (1100 yards) and upwards would appear to be solved. In the square of St. Dominique, at Perpignan, a boring had been carried on upon the old method for upwards of eleven months for the purpose of forming an artesian well, and the water had not been found." Fauvelle placed his new tube alongside the old boring tackle, and soon got down to a depth of nearly 100 yards, when an accident occurred which would have required some days to remedy. Fauvelle decided upon abandoning the bore-hole already sunk so deep, and commencing a new one, satisfied that there would thereby be a saving in time. The rate of sinking was equal to four English feet per hour of the time the hollow boring rod was actually at work, the depth of 560 English feet having been obtained in 140 working hours, for a bore-hole of about six English inches in diameter. M. Arago, who had seen the rods of Fauvelle at work, mentions how fully they answered, and that the large powerful tools at the bottom of the hollow boring rod cut easily through the hardest strata; he confirmed the fact of the large-sized stones and gravel coming up with the ascending current, having himself watched them. He also mentioned that such was the opinion of the people in the vicinity of Perpignan, and so much was water wanted that orders for the sinking upwards of 200 artesian wells had been given to Fauvelle. The introduction of this system into this country, especially if combined with the Chinese or percussive system of boring as practised with bore-holes of very large diameter at the Saarbruck mines, and at many other places on the Continent, must be productive of great benefit, and would not merely effect a saving of money and labour, but the paramount advantage of immediately solving the question of the existence of coal, minerals, water, &c.

On Mechanical Apparatus employed for the purpose of preventing Incrustation of Steam Boilers. *By* Mr. Lamb.

It may be defined as a self-acting blow-off apparatus. Mr. Lamb has a theory that "blowing-off" should take place near the top of a boiler rather than from the bottom. He conceives that the carbonate of lime floats by means of small bubbles of steam adhering to each particle of lime. His contrivance consists of a large copper float closing the orifice of a blow-off pipe in the boiler. When the water has risen above a certain height, the blow-off valve is opened by the float, and so delivers the boiler

of its excess of water. This hot water passes through a cylindrical chamber round the feed-water, so as to heat it on entering. The apparatus is simple, and is stated to have worked perfectly well.

Experiments on the Tubular Bridge proposed by Mr. Stephenson *for crossing the Menai Straits. By* W. Fairbairn.

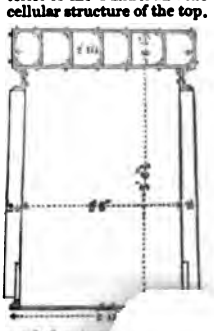


Elevation, showing a side view of the Tube, the supports at the ends, and the weight W in the middle.

The experiments undertaken to ascertain the best form of bridge for carrying the Chester and Holyhead Railway across the Menai Straits have led to valuable and important results. They have put us in possession of facts which will greatly increase our knowledge of the properties of a material whose powers of combination were but imperfectly understood; for, exclusive of the rapidly increasing use of wrought iron in the construction of ships, boilers and other vessels, its application to bridges of the tubular form is perfectly novel, and originated with Mr. Robert Stephenson. Experiments of the most conclusive character were those made upon a model tube of a large scale, containing nearly all the elements of the proposed bridge, and the various conditions with regard to form and construction which had been developed by the previous inquiries. At first it occurred to Mr. Fairbairn that the strongest form would be that wherein the top and bottom consisted of a series of pipes, with riveted plates on their upper and lower sides. This form of top would possess great rigidity, and is well-adapted to resist the crushing forces to which it is subjected; and the bottom section appeared equally powerful to resist tension. Mr. Fairbairn is inclined to think that this is the strongest form that can be devised; but practical difficulties present themselves in its construction, as an easy access to the different parts for the purposes of painting, repairs, &c. is absolutely necessary. The scale of the model tube is exactly one-sixth of the bridge across one of the spans of the Straits, 450 feet*; it is also one-sixth of the depth, one-sixth the width, and, as near as possible, one-sixth the thickness of the plates. With these proportions and form, the experiments proceeded as follows:—In each of the experiments the weights were laid on about a ton at a time; and the deflection was carefully taken, as well as the defects of elasticity after the load was removed.

Rectangular model tube, 80 ft. long, 4 ft. 6 in. deep, 2 ft. 8 in. wide, and 75 ft. between the supports.—Thickness of the plates: bottom, ·156 in.; sides, ·099 in.; top, ·147.—Sectional area of the bottom, 8·8 in., and the weight of the tube 10,888·9 lbs.=4·86 tons.

Enlarged and Transverse Section, showing the interior of the Tunnel and the cellular structure of the top.



First experiment. Breaking weight, 79,578 lbs.=35¼ tons.—Ultimate deflection, 4·375 inches.—Permanent set, or defects of elasticity, with a weight of 67,842 lbs., ·792 inch.—With the above weight, 35¼ tons, the bottom was torn asunder direct across the solid plates at a distance of 2 feet from the centre of the shackle from which the load was suspended. One of the principal objects of this inquiry was to determine the ratio or proportion between the top and bottom sides of the tube. Taking the experiment immediately preceding, it was found that the area of the top

* The span has since been increased to 462 feet.

the bottom, in a rectangular tube, should be as 5 to 3. These proportions were deduced from the experiments on the smaller description of tubes, or those having the corrugated top, and thick plates on the upper sides. The plates forming the top of the model tube were rather thicker than intended, and consequently gave (according to the former experiments) a preponderating power of resistance to that part. To obviate this disparity, two additional strips, 6½ in. by 5-16ths in. thick, about 4 cwt., were riveted along the bottom to an extent of 20 ft. on each side of the shackle. This increase raised the area of the bottom to nearly thirteen inches, being about the ratio of 5 to 3 or 23·5 to 13. With these proportions, and having repaired the fractured part by the introduction of some new plates, the experiment proceeded as before.

Second experiment. Breaking weight, 97,102 lbs.=43·3 tons.—Ultimate deflection, 4·11 inches.—Permanent set could not be taken. In this experiment the tube failed, by one of the ends giving way, which caused the sides to collapse. The weak point in this experiment was evidently a want of stiffness in the sides. To remedy this evil, and keep them in form, a number of vertical ribs, composed of light angle iron, were riveted along the interior of each side, at distances of 2 ft.; and having again restored the injured parts, the tube was a third time subjected to the usual tests.

Third experiment. Breaking weight, 126,138 lbs.=56·3 tons.—Ultimate deflection, 5·68 inches.—Permanent set, or defects of elasticity=1·96 in. After suspending a weight of 121,443 lbs., the platform unfortunately gave way, causing an interruption to the experiment. This was, however, speedily repaired, and the experiment continued, when the tube was ultimately torn asunder, through the bottom plates, by a weight of 126,138 lbs. The above experiment was one of the most satisfactory description, as, at the moment of fracture, the cellular top gave evident symptoms of yielding to a crushing force, by the puckerings of each side, which were gradually enlarged as the deflection increased. These appearances became more apparent as the joints of the plates on the top side had cut a number of the rivets in two, and the holes had slid over each other to an extent of nearly 3-10ths of an inch. The conclusive nature of the whole of the experiments on the model tube is highly satisfactory: they exhibit extraordinary powers of resistance; and considering that the weight of the whole material contained in the tube does not exceed 5 tons; that the distance between the supports is 75 ft.; and the load in the middle 11 times its own weight, or 22 times if equally distributed, it is probably not over-rating its powers to state that hollow beams of wrought iron, constructed on this principle, will be found (whether used for bridges or for buildings) about three times stronger than any other description of girders.

Experiments on the Tubular Bridge proposed by Mr. Stephenson *for crossing the Menai Straits. By* E. Hodgkinson, *F.R.S.*

Finding that a number of experiments had been made upon cylindrical and elliptical tubes, and a few upon rectangular ones, Mr. Hodgkinson expressed a conviction that the tubes then tried and others proposed, would not be the best for the intended purpose, though they would afford valuable introductory knowledge. He urged that the tube, to bear the greatest weight, must be formed as a large beam or girder, having its top and bottom equally capable of resistance, and with sides strong and stiff enough to keep them at their proper distance; and as it was found that the tube usually gave way at the top by buckling, and hence would require additional metal, and might perhaps be very heavy, he suggested that the top should be formed of cylindrical tubes, as he felt that these tubes, or something analogous to them, would best resist the strain to which the top would be exposed. The following are some of the leading results; and, first, those from the fracture of two *similar* tubes, as in the following table:—

Length of Tube.		Weight of Tube.		Distance between supports.	Depth of Tube.	Breadth of Tube.		Thickness of metal in 16ths of an inch.			Breaking weight in Tons.
ft.	in.	cwt.	qr.	ft.	ft.	ft.	in.	Top.	Bottom.	Side.	
31	6	20	3		2	1	4	6	4	2	26·1
47	0	61	0	45	3	2	0	9	6	3	65·5

The ultimate deflexion of the former tube was about 2¼ in., and that of the latter about 3¼ in. To ascertain the power of such a tube to bear a side strain—as from the action of the wind—the smaller tube above, after being well-repaired, was laid on its side, and broken, from a mean of two experiments, with 15·2 tons. Hence its *lateral* strength was $\frac{1}{16}$ of its *vertical* nearly; and in a narrower tube it would be considerably less. A number of experiments were made to determine the resistance of plates of wrought iron to a force of compression; and from these considerable information has been obtained with respect to the laws of their resistance to flexure or buckling. The following table contains the weights, external dimensions, and weights of greatest resistance of some of the tubes 10 feet long, which were subjected to a force of compression :—

Weight of Tube.	External Diameter of Tube.	Weight of greatest resistance.
CYLINDRICAL TUBE.		
lbs. oz.	inches.	lbs.
47 10	2·34	31,828
45 15	2·99	37,356
59 0	4·05	47,212
64 4	4·06	49,900
RECTANGULAR TUBE.		
43 14¼	4·1×4·1	19,646
65 8	8·5×4·1	23,289
82 0	8·1×4·1	43,673
91 1	8·0×8·0	27,545

The rectangular tubes above are all of plates $\frac{1}{16}$th of an inch thick. They were all simple rectangles or squares, except the last but one, which had a division in it, making it into two squares. The proposed tubular bridge has undergone alterations in consequence of Mr. Hodgkinson's experiments and recommendations :— 1st. In the thickness of the side to enable it better to resist the action of the wind. 2nd. In the top being made straight, instead of curved, to allow the escape of the steam. 3rd. In reducing the rectangular cells at the top. In this last instance, however, since rectangular tubes are weaker than square ones to resist compression, and these much weaker than cylindrical tubes, Mr. Hodgkinson hopes the latter will be substituted for the former; as it would, according to the preceding experiments, effect a saving of one-fourth of the metal in the top, leaving the strength the same. This matter is of the more consequence, as the weight of the tubular bridge will bear so large a proportion to the breaking weight.

Mr. Clarke, the resident engineer of the proposed Menai Bridge, read a statement of the principles on which the model tubes for the tubular bridges, on the Holyhead Railway, should be increased to larger dimensions.

On the Law which governs the Resistance to Motion of Railway Trains at High Velocities. *By* J. Scott Russell, *M.A., F.R.S.E.*

Having on former occasions communicated the results of experimental researches concerning the resistance experienced by floating bodies moving along the surface of water at high velocities, I have thought it not an inappropriate sequel to communicate the general result of a long series of experiments, made partly by committees of this Association, and partly by myself. The subject of the resistance which requires to be overcome in order to give motion to trains at high velocities has been matter of great uncertainty, some dispute, and the cause of several grave errors in practical engineering. Some six years ago a committee of the Association was appointed to make experiments on this subject, and these experiments were at the time a valuab[le] addition to our knowledge. They showed that the resistance at such velocities as miles an hour was much greater than had been supposed—at least double.

committee, however, in concluding their labours, stated that they were not able to deduce from them any law, or semblance of a law; that the resistance increased with the velocity, but it did not appear to do so according to any simple function of the velocity, neither as the velocity directly, nor as the square of the velocity. Since that time the question has been a *quæstio vexata* among practical men and mathematicians. A paper read at the Royal Society last winter comes to the same conclusion as the old committee of the British Association, viz. that no law is manifested in the experiments, of which at high velocities the results are quite anomalous. The consequences of errors on such a point have become now so serious, especially where velocities of 50 or 60 miles an hour are attempted, that it has been thought desirable that the question should be, if possible, thoroughly resolved. For this purpose I have undertaken a series of practical experiments, on a large scale, with railway trains of a great variety of size and weight, and at velocities as high as 61 miles an hour. They were made on the South-Western, London and Brighton, South-Eastern, Sheffield and Manchester, and Croydon Atmospheric Railways. I have combined with these the experiments formerly made by the British Association, and some by Mr. Harding on the broad gauge; and it is the result of this great variety of facts which I wish to lay before the Section. The experiments themselves are arranged in the following table:—

No. of Experiment.	Uniform velocity maintained in miles per hour.	Resistance in lbs. per ton by Experiment.	Resistance in lbs. per ton by Formula.
1	10	8·40	9·30
2	14	12·60	13·90
3	14	12·60	13·90
4	29	16·50	15·70
5	31	23·30	25·40
6	31	18·20	16·30
7	32	22·50	27·20
8	33	22·50	22·70
9	33	15·68	16·90
10	33	15·96	17·00
11	34	16·60	17·30
12	34	16·95	17·30
13	34	17·70	17·30
14	34	23·30	27·20
15	34	25·00	23·10
16	35	22·50	26·10
17	36	22·50	22·40
18	36	22·40	21·50
19	37	17·50	18·20
20	37	25·00	28·40
21	39	30·00	31·00
22	41	22·99	19·60
23	41	26·78	19·60
24	45	21·70	21·00
25	46	23·10	21·30
26	46	30·31	31·00
27	47	33·70	33·10
28	50	32·90	36·30
29	51	26·40	23·00
30	53	41·70	42·10
31	61	52·60	54·80

These experiments show the great amount of resistance at high velocities; but they also show the apparent anomaly of the results. We have many higher velocities than others with much lower resistances. These are the difficulties in the way of any simple and apparent solution. The method of investigation I have adopted is this—I have taken all the results of experiments, and removed from them, in the

first instance, all the questionable experiments. I found it necessary to discard all the experiments made with accelerating velocities, and to retain only such as were made on uniform velocities, in the same circumstances, over a large space; most of my own experiments having a steady uniform velocity over from one mile to six. I have also selected those which were most free from the action of wind—an element of much importance. By thus weeding out the experiments, and taking only the most unquestionable, I simplified the subject very materially. Those which remain are given in the table. In this table the weight of each train in tons is shown, and the number of pounds of force required to keep each ton weight of that train in motion at a given number of miles per hour, is shown by actual experiment. The analysis of those experiments I made as follows :—I take the friction of the axles and wheels as an ascertained quantity equal in the best-conditioned carriages to 6 lbs. per ton of train. This I conceive we may consider to have been proved by all experiments of friction, including those of Mr. Morin, the latest and best, to be a source of resistance constant at all velocities. This I call friction proper, and I consider it as the first element of resistance. Friction proper, the first element of resistance,—or

$$R_1 = C\,m, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [1.]$$

where C = 6 lbs., and m = the mass of the train in tons weight.

The second element of resistance is the resistance of the air to the front of the train. This has been variously estimated, and somewhat erroneously. Some persons have taken for it Smeaton's tables of the force of the wind. But such a table gives a quantity quite in excess; for these tables were made from the force of the wind upon a *thin* plate, a case where the minus pressure behind is added to the plus pressure before the plate; whereas, in the case of the railway train, there is a solid body, whose third dimension extends the whole length of the train. I have therefore taken, not the table of the force of the wind, but a table of the resistance of air calculated from the height due to the velocity, which I have found to represent most accurately the resistance of fluids to bodies passing through them; and I have taken this as the second essential element in the resistance to railway trains. Resistance of the air, the second element:—

$$R_2 = A p v^2, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [2.]$$

where A = the area in square feet of the front of the train, and p = weight of a column of air, whose base is a square foot, and whose length is the height due to the velocity of one mile an hour; v being the velocity of the train.

After having deducted from the results of the experiments the sum of these two resistances, I have found a large amount still unaccounted for; and I find this quantity to be not only large, but dependent also on the velocity. The question which I now submit to the Section is the determination of the nature and cause of this third element of resistance. The third element of resistance appears by the experiments to increase very nearly as the velocity, simply; that is, it amounts at 10 miles an hour to about 3 lbs., at 30 miles an hour to 10 lbs., and at 60 miles an hour to 20 lbs. per ton. It is therefore proportioned to the mass or weight of the train and to the velocity jointly. Other resistances due to velocity or third element:—

$$R_3 = B\,m\,v, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [3.]$$

where $\frac{1}{4}$ lb., m the weight of the train in tons, and v its velocity in miles an hour. Whence the total resistance (R) to any train of any weight moving with any velocity is to be obtained from the formula

$$R = R_1 + R_2 + R^3 = A\,p\,v^2 + B\,m\,v + C\,m. \quad . \quad . \quad . \quad . \quad . \quad [4.]$$

The results of this formula are shown in the last column of the table; and from the close manner in which they follow the experiments through their various and apparently anomalous results, they may be regarded as an approximation to the truth sufficiently close for all practical purposes. The next question discussed was the nature of this third element—resistance. The author attributed it mainly to the concussions, oscillations, frictions and flexures to which all the portions both of the train and permanent way are subject, at high velocity.

Modification of Dr. Whewell's *Anemometer for measuring the velocity of the Wind.* *By* the Rev. T. R. Robinson, *D.D., M.R.I.A.*

The author explained briefly to the Section the nature of the various anemometers which have hitherto been used. Most of them measure the pressure of the wind, and

Osler has contrived an arrangement by which this is registered in connexion with the time and the direction. Meteorologists however are chiefly interested about the velocity, or rather the actual space traversed by atmospheric currents. The velocity *at any instant* can be computed from the *observed* pressure; but the *mean* velocity for a given period cannot easily be derived from the mean pressure. But Whewell's instrument gives the desired result immediately, recording the space itself. As constructed by him, however, it is liable to errors, which Mr. Snow Harris pointed out at the Plymouth meeting; at the same time producing a series of observations which seemed so important to Dr. Robinson, that he endeavoured to contrive a machine which should perform the same office more precisely, and whose indications should have an invariable value. He was enabled to do this by the application of a fact which he learned from the late Richard Lovell Edgeworth, Esq.: if hemispherical cups be carried by horizontal arms attached to a vertical axis, with their diametral planes vertical, they constitute an effective windmill, which Dr. Robinson has found revolves *with one-third of the wind's velocity*. To the bottom of the axis is attached wheelwork actuating a revolving disc, which rotates through a degree for every mile traversed by the wind. A pencil moved in the direction of the radius by clockwork, at the rate of half an inch per hour, traces on paper fixed on this disc the curve of space and time. A similar disc connected with a powerful vane records the curve of direction and time; as however such vanes (especially in high winds) are in perpetual oscillation, there is attached to it a regulator consisting of a small water-wheel revolving in a cistern, with a speed five times that of the vane. This of course obeys any slow change of direction without difficulty, but presents so great a resistance to any rapid shift, that the eddies are past before it yields. This, though not absolutely, yet in a great measure, steadies the vane. The machine erected at the Armagh Observatory acts in a very satisfactory manner, moving when no air of wind can be felt, yet acting with perfect steadiness in severe gales, during one of which Lind's gauge showed a pressure of 2⅛ inches of water. He then explained how the daily results were to be summed up by resolving them according to axes of coordinates directed to the north and east, and illustrated the method by exhibiting the process for the first six months of the current year.

On the Sailing Powers of two Yachts, built on the Wave Principle. *By* J. PHIPPS, *M.D.*

The *first* was built for Dr. Corrigan, of Dublin, in 1844; a small open boat 24 feet by 6, of 3¼ tons, which did so well that she was able to beat everything near her own size, and to sail with those which exceed it in some instances as far as four times. She was dry in seas where they were wet, was very stiff, sure in stays, and steered well at all times. The *second* is a yacht of 45 tons, O.M., for Samuel Hodder, Esq., of Ringabella; built from the drawing by Mr. Peasley, of Passage West, in Cork. She appears to have the following qualities: a first-rate performance, attained without sacrifice of any good quality, large accommodation, and high stability. She is weatherly, steady and easy, dry in the worst weather, and pitches and ascends less than any vessel I was ever in. She turns so sharply that no 10-ton yacht can do it quicker, and steers so well, scudding in a gale of wind, that notwithstanding an unbalanced state, from an injudicious shift of mast, she neither broaches to nor is compelled to lay to, which a companion of larger size (60 tons), and of tried sea qualities, was forced to do, and, in consequence, arrived from Cork to Dublin 14 hours after the Wave-built yacht. In a race at Kingstown for the Railway Cup of 100 guineas, in which she was matched against the best boats of the three countries, in a time race, including one fine yacht of 100 tons, she won—and did the course exactly in 4 h. 22 m. 58 s.—it being 46 nautic miles. Making no allowance for tacking or starting from absolute rest, the rate of this is 10¼ knots per hour. This is a great result for a principle yet in its infancy. The same vessel left Holyhead in a gale of wind, with storm-sails, main-sail stowed, and everything made snug; with a reefed try-sail, a double-reefed fore-sail, and third jib. She lay in one stretch to the Irish coast, where she tacked to the southward, beating down to the Arklow light in 11 hours. Six persons on board, being separately questioned, agreed that the time from Holyhead to the Irish coast was 4¼ hours. Making every reasonable allowance, less than 50 nautic miles could not have been done; and this gives a velocity of 11 nautic

miles per hour,—an unrecorded speed for ships of any size, close hauled, but surprising for a vessel of 45 tons, and in a very rough sea. It was, in fact, remarked on board, that, as the wind freshened, her pace increased without limit. This agrees with the fact stated by Capt. Fishbourne of the Flambeau steamer, on wave lines, that she had a speed greatest in the worst weather, as compared with her rival. It is perhaps possible to improve sailing vessels greatly, as compared with steamers. When so improved, they might be used where sailing vessels nearly compete with steamers at present. This may be further helped by the diminution of insurance and of the present unnecessary waste of human life.

Mr. Bodmer communicated the result of experiments on long and short stroked steam-engines.

Mr. Clarke exhibited the model of a new atmospheric tube, in which the sides are elastic enough to close the slit and form a self-acting valve.

Dr. Bevan exhibited his mode of applying atmospheric air to propulsion.

Mr. Eyton exhibited the model of a compact form of vertical steam-engine, which possessed the advantage of a long connecting-rod. The plan was not quite original, but he had applied it with advantage.

On Vulcanized Caoutchouc. By W. Brockedon, *F.R.S.*

Mr. Brockedon stated that the discovery in this country was due to Mr. Hancock of the firm of C. Macintosh and Co., Manchester, and that he made it whilst experimenting to fuse caoutchouc and sulphur together. He found that though the sulphur was at 300°, the rubber, which alone would have melted at about 220° and absorbed the sulphur, was thus protected from melting. A chemical union of a certain portion of the sulphur with the caoutchouc took place; and it was found that this process might be carried far enough to carbonize the caoutchouc to the condition of horn, but never to melt it. Mr. Hancock then united sulphur mechanically with rubber; and also dissolved sulphur in the solvents of caoutchouc; and heating these materials so prepared to the necessary degree, found that the change was effected called *vulcanized*. The new properties which rubber thus acquires are most important in the hands of mechanical engineers, from the increased and permanent elasticity of the vulcanized rubber; it is being brought into extensive application and use for railways, lying between the rail or the chair and the sleeper; for the drag and buffer springs and side springs of railway carriages, waggons and trucks; for washers for steam, gas, and water-pipes, being permanently elastic at low temperatures as well as at very high; even for steam pipes at 50 and 60 lbs. to the inch, they have formed a perfect joint. A Nasmyth steam-hammer of 5 tons weight has fallen 18 inches on a piece ¼ an inch thick and 2 inches square without any injury to the form of the rubber. A cannon-ball resting on a piece of vulcanized rubber 1 inch thick has been crushed and broken without leaving, except upon close examination, any trace of its effects on the rubber, when a hole like a leech-bite might be found which had closed after the blow. The layer of corrugated rubber, which had been placed between the rail and the sleeper, after two years' service on the Great Western Line, betrayed no trace of injury or effect of pressure.

Upon this new material the solvents of common rubber have no longer the action of solvents; the rubber slowly absorbs them but is not dissolved by them, and when the essential oils are evaporated the vulcanized rubber regains all its strength and elasticity. Its elasticity is permanent and invariable; no cold of our climate has any power to harden it, or the heat of any climate to injure it. These are properties which cannot fail of bringing it extensively into use in the mechanical arts.

On a Machine for registering the Velocity of Railway Trains. *By* M. Ricardo.

The object of it is to furnish the railway companies with a record of the work done by each train, and the measure in which it has been done. By this means they would be often enabled, in case of any accident, to assign correctly the nature and cause of the accident; and so prevent its recurrence. He also showed the work of a machine for registering the resistance of trains.

On the Comparative Value of the different kinds of Gas Meters now in use. *By* J. Sharp.

ETHNOLOGY.

Notice on the Aborigines of Newfoundland. *By* J. Beete Jukes, *M.A., F.G.S.*

In this paper the author stated that, from all the information he procured in Newfoundland in the years 1839 and 1840, he believed the aborigines of that country to be a branch of the Red Indians of North America, and that they had no affinity with the Esquimaux; that they were acquainted with the Esquimaux, and despised them for their dirty habits; that they were on friendly terms with the mountaineers of Labrador, whom they called Shaunamunc; and that about twenty years ago the last remnant of the Bœothics, or Aborigines of Newfoundland, were probably received by the mountaineers and incorporated into their tribes.

Notes on the three Races of Men inhabiting the Islands of the Indian and Pacific Oceans. *By* J. Beete Jukes, *M.A., F.G.S.*

In this paper the author stated his belief, derived from personal observation, that in the islands included between the eastern coast of Africa and the western coast of America, there were at least three races of men:—1st. The Malayo-Polynesian race. 2nd. The Papuan race. 3rd. The Australian race.

He believed that these three races would be found to differ one from the other, physically, morally and intellectually. He then detailed some of these differences, and showed that whichever class of characters were taken, the differences between the races became equally strongly marked. As a good external physical mark, the hair might be taken; when the first race might be called the straight-haired; the second, the frizzle-haired; and the third, the curly-haired. The author entered somewhat at length into a comparison of the manners and customs of the two latter races, as they had hitherto often been confounded together, and showed that there was as strongly marked a distinction, whether the structure and aspect of the body, the disposition or powers of the mind, or the habits and customs, arts, implements, and weapons of the people were taken as the standard of comparison, between the second race and the third as between the second and the first. He stated that the third race, or Australian, was strictly confined to the continent of Australia, and the islands immediately adjacent to its shores. He described the second, or Papua race, as stretching from Mangeray or Flores, through Timor, New Guinea, and the adjacent islands, the Louisiade, the Solomon Archipelago, the New Hebrides, and New Caledonia, to the Fejee Islands. Some outlying tribes of this race might be found, perhaps, in islands to the west of Flores, and the inhabitants of the Andamans apparently belonged to them; and even some of the hill tribes of the interior of India seemed to resemble them. On the south-east again they seemed to have reached Van Diemen's Land, and mingled there with the Australian race. The first race, or the Malayo-Polynesian, occupied all the other islands, namely, Madagascar, Sumatra, Java, Borneo, Celebes, the Philippines, Carolines, Friendly Islands, New Zealand, and all the other islands to the eastward over the whole Pacific Ocean. The principal object of the paper

was stated to be the separation of the Australian race from the Papuan; the differences between them being quite as strongly marked as between the Papuan and the Malayo-Polynesian.

On a Vocabulary of the Bethuck Indians of Newfoundland. *By* R. G. LATHAM, *M.D.*

The evidence of language is in favour of the ethnographical affinities of the native Indians of Newfoundland being with the Red Indian rather than the Esquimaux tribes.

On the Nekrasowzers of Bessarabia. *By* W. TWINING, *M.D.*

A small Cossack race, which chiefly supports itself by fishing, and after having been engaged in hostility with all its neighbours, settled in Russia in 1830.

On the Natives of Timor and Macassar. *By* Mrs. SHORT.

The former are of dark complexions, of five feet six inches in height, and well-proportioned. They are inclined to gambling, slaving, and drinking; they are ingenious artificers and careful of the dead. They worship the devil, and are very superstitious. Their dress is picturesque. The people of Macassar are superior physically to the natives of Timor; their deportment is bold and independent, and eye beautifully fierce. Great attention is paid by the females to the dressing of their hair. They indulge in cock-fighting; but are industrious and take great pride in the neatness of their houses and gardens. The tribe of the people of Macassar designated Bugis, are a very commanding people, and ornament themselves with valuable jewellery. They are very susceptible of insult and revengeful.

On the present state of Ethnological Philology. *By* R. G. LATHAM, *M.D.*

On certain Races of Siberia. *By* Professor Von MIDDENDORFF.

1. *Ostiacks.*—The most eastern branch of the Finnic stock. Between the Finns and Mongols, as spread over continuous areas, the Yenisey is the boundary. East, however, of the Yenisey, on the Kureika River, is found a small detached Ostiack horde. A nomade tribe, still more to the east, although called Ostiack, is probably Samoeide.

2. *Samoeides.*—According to physical conformation, the Samoeides are Mongol. Two Samoeide languages, each falling into various dialects, are spoken on the Lower Yenisey. The Samoeides of the White Sea are the type of the race. The Yuracks, or Samoeides, on the west of the Yenisey, have a Finnic character. The Chatanga River forms the eastern boundary on the Samoeides.

3. *Tungusians.*—Three or four main dialects. Three varieties of physical conformation.

4. *Yakuts.*—The antagonism between the evidence of language and the evidence of physical conformation is here even stronger than in the case of the Samoeides; the language being Turk, the physiognomy Mongol. The Yakuts are pre-eminent examples of the extent to which the habits and constitution accommodate themselves to change of locality and climate. Originally inhabitants of the Central Asiatic Steppes, destitute of trees, their second habitation was the region of woods, and their third the borders of the Polar sea. Their first domestic animal was the horse, their second the rein-deer, and their third the dog. The Dolganen are an outlying tribe of Yakuts, hitherto undescribed, on the Yenisey.

5. *Yukagirs.*—Only two individuals seen; their physical characters those of the Yuracks.

6. *Ainos.*—Locality, the left bank of the mouth of the Amur; name, Gilacken; physiognomy, Caucasian, sometimes Japanese. The two characters occasionally found even in the same family.

7. *Kachkhall.*—On the south bank of the Amur. Known only from the descrip-

tions of the Ainos. Stature, short; the lower extremities being disproportionately so. The further investigation of these tribes is important; inasmuch as they may represent the Samoeide varieties of the Icy Sea, in a more southern and eastern locality.

On the Ethnographical Distribution of Round and Elongated Crania. By Professor Retzius.

The development of the occipital bone determines that character of the cranium which may be called *Dolichocephalic.*

The development of the parietal bones determines that character of the cranium which may be called *Brachycephalic.*

The Celtic nations are pre-eminently *dolichocephalic*, the Finnish *brachycephalic.*

Furthermore, nations with a perpendicular profile are *orthognathic*; nations with a retiring profile are *prognathic.* Of the former, the Greeks, Romans, Germans, &c. are the type; of the latter, the Negro.

Hence the classification into—

European.

1. *Gentes dolichocephalæ orthognathæ*—The Scandinavians, Germans, Gaels, &c.
2. *Gentes brachycephalæ orthognathæ*—Laps, Finns, Slaves, Turks, &c.

Asiatic.

1. *Gentes dolichocephalæ orthognathæ*—Hindoos, Georgians, Arabians, &c.
2. *Gentes brachycephalæ orthognathæ*—Samoeides, Yakuts, Buriats, &c.
3. *Gentes dolichocephalæ prognathæ*—Chinese, Japanese.
4. *Gentes brachycephalæ prognathæ*—Calmucks, Tartars (?), Malays, &c.

Polynesian.

1. *Gentes brachycephalæ orthognathæ*—The Tagals of the Manillas.
2. *Gentes dolichocephalæ prognathæ*—Australians, New Zealanders, &c.
3. *Gentes brachycephalæ prognathæ*—Tahitians, Malays, Papuans.

African.

1. *Gentes dolichocephalæ orthognathæ*—Guanches, Berbers, Nubians, Abyssinians; transitional to the *g. prognathæ.*
2. *Gentes dolichocephalæ prognathæ*—Copts, Caffres, Hottentots, Negroes in general.

American.

1. *Gentes dolichocephalæ prognathæ*—Eskimos, Colooches, Cherokees, Iroquois, Hurons, Chiccasaws, Cayugas, Algonkins,—Botocudos, Caribbs, Guaranis, Aymaras, Patagonians.
2. *Gentes brachycephalæ prognathæ*—Natchez, Creeks, Uchees, Clatsops, Ioways—Charruas, Puelches, Araucanians, Modern Peruvians.
3. *Gentes brachycephalæ orthognathæ*—Atzecks (?), Incas of Peru (?)

On the Comanche Indians. By W. Bollaert.

These the author stated to be a Texian tribe of native Indians, who were divided into three divisions:—1. The Comanche or Jetan. 2. The Lemparack. 3. The Tenuha. They constituted the largest native tribe in Texas; they possessed few traditions, and were unacquainted with agriculture; consequently their habits were migratory. During war, they acknowledged one chief; they had an idea of a future state, but of a very gross nature, believing in the existence of evil spirits and witchcraft. The author, in conclusion, gave some remarks on their mode of conducting war, and on their treaties.

On the Indian Tribes of Texas. By W. Bollaert.

This consisted of an enumeration of the distinct tribes which were now, or had been known in Texas. They formed a catalogue of thirty-five tribes. Some of these were derived from the Comanches—others were either wholly or nearly extinct. The manners of a few of the most considerable were alluded to.

On a Comanche Vocabulary. *By* R. G. LATHAM, *M.D.*

From the evidence of two scanty vocabularies, the Comanche language appears to be closely allied to that of the Shoshonie or Snake Indians.

On the Origin of the Modern Greeks. *By* G. FINLAY.

On the Tasmanians. *By* H. B. DAVIES.

On the Africans of the neighbourhood of Bonny. *By* Capt. BRIAN.

On the Inhabitants of Prince's Island. *By the* Rev. J. FREEMAN.

On the Inhabitants of Port Essington. *By* Mrs. SHORT.

On the Delta and Alluvial Deposits of the Mississippi, and other points in the Geology of North America, observed in the years 1845–46. *By* CHARLES LYELL, *M.A., F.R.S. and V.P.G.S.*

(A Discourse delivered at the Evening Meeting, Monday, Sept. 14, 1846.)

The delta of the Mississippi may be defined as that part of the great alluvial plain which lies below or to the south of the branching off of the highest arm of the river called the Atchafalaya. This delta is about 14,000 square miles in area, and elevated from a few inches to ten feet above the level of the sea. The greater part of it protrudes into the Gulf of Mexico beyond the general coast-line. The level plain to the north, as far as Cape Girardeau in the Missouri, above the junction of the Ohio, is of the same character, including, according to Mr. Forshey, an area of about 16,000 square miles, and is therefore larger than the delta. It is very variable in width from east to west, being near its northern extremity, or at the mouth of the Ohio, 50 miles wide, at Memphis 30, at the mouth of the White River 80, and contracting again further south, at Grand Gulf, to 33 miles. The delta and alluvial plain rise by so gradual a slope from the sea as to attain at the junction of the Ohio (a distance of 800 miles by the river) an elevation of only 200 feet above the Gulf of Mexico.

Mr. Lyell first described the low mud-banks covered with reeds at the mouths of the Mississippi and the pilot-station called the Balize; then passed to the quantity of drift-wood choking up the bayons or channels intersecting the banks; and, lastly, enlarged on the long, narrow promontory formed by the great river and its banks between New Orleans and the Balize. The advance of this singular tongue of land has been generally supposed to have been very rapid; but Mr. Lyell, and Dr. Carpenter who accompanied him, arrived at an opposite conclusion. After comparing the present state of this region with the map published by Charlevoix 120 years ago, they doubt whether the land has on the whole gained more than a mile in the course of a century.

A large excavation eighteen feet deep, made for the gas-works at New Orleans, and still in progress in March 1846, shows that much of the soil there consists of fine clay or mud, containing innumerable stools of trees, buried at various levels in an erect position, with their roots attached, implying the former existence there of fresh-water swamps covered with trees, over which the sediment of the Mississippi was spread during inundations, so as slowly to raise the level of the ground. As the site of the excavation is now about nine feet above the sea, the lowest of these upright trees imply that the region where they grew has sunk down about nine feet below the sea-level. The exposure also in the vertical banks of the Mississippi at low water, for

hundreds of miles above the head of the delta, of the stumps of trees buried with their roots in their natural position, three tiers being occasionally seen one above the other, shows that the river in its wanderings has opened a channel through ancient morasses, where trees once grew, and where alluvial matter gradually accumulated. The old deserted bed also of the river, with its banks raised fifteen feet above the adjoining low ground, bears testimony to the frequent shifting of the place of the main stream, and the like inference may be drawn from the occurrence here and there of crescent-shaped lakes, each many miles in length, and half a mile or more in breadth, which have once constituted great curves or bends of the river, but are now often far distant from it.

The Mississippi, by the constant undermining of its banks, checks the rise of large commercial towns on its borders, and causes a singular contrast between the wealth and splendour of 800 or more fine steamers, some of which may truly be called floating palaces, and the flat monotonous wilderness of uncleared land which extends for hundreds of miles on both sides of the great navigable stream.

Mr. Lyell visited, in March 1846, the region shaken for three months, in 1811–12, by the earthquake of New Madrid. One portion of it, situated in the States of Missouri and Arkansas, is now called "the sunk country." It extends about seventy miles north and south, and thirty east and west, and is for the most part submerged. Many dead trees are still standing erect in the swamps; a far greater number lie prostrate. Even on the dry ground in the vicinity, all the forest trees which are of prior date to 1811 are leafless; they are supposed to have been killed by the loosening of their roots by the repeated shocks of 1811–12. Numerous rents are also observable in the ground where it opened in 1811, and many sink-holes or cavities, from ten to thirty yards wide and twenty feet or more in depth, now interrupt the general level of the plain, which were formed by the spouting out of large quantities of sand and mud during the earthquake.

In attempting to compute the minimum of time required for the accumulation of the alluvial matter in the delta and valley of the Mississippi, Mr. Lyell referred to a series of experiments made by Dr. Riddell at New Orleans, showing that the mean annual proportion of sediment in the river was to the water $\frac{1}{1245}$ in weight, or about $\frac{1}{2000}$ in volume. From the observations of the same gentleman and those of Dr. Carpenter, and of Mr. Forshey, an eminent engineer of Louisiana, the average width, depth and velocity of the Mississippi, and thence the mean annual discharge of water are deduced.

In assuming 528 feet (or the tenth of a mile) as the probable thickness of the deposit of mud and sand in the delta, Mr. Lyell founds his conjecture on the depth of the Gulf of Mexico, between the southern point of Florida and the Balize, which equals on an average 100 fathoms. The area of the delta being about 14,000 square statute miles, and the quantity of solid matter annually brought down by the river 3,702,758,400 cubic feet, it must have taken 67,000 years for the formation of the whole; and if the alluvial matter of the plain above be 264 feet deep, or half that of the delta, it has required 33,500 more years for its accumulation, even if its area be estimated as only equal to that of the delta, whereas it is in fact larger. If some deduction be made from the time here stated, in consequence of the effect of drift-wood, which must have aided in filling up more rapidly the space above alluded to, a far more important allowance must be made on the other hand for the loss of matter owing to the finer particles of mud not settling at the mouth of the river, but being swept out far to sea, and even conveyed into the Atlantic by the gulf-stream. Yet the whole period during which the Mississippi has transported its earthy burthen to the ocean, though perhaps far exceeding 100,000 years, must be insignificant in a geological point of view, since the bluffs or cliffs bounding the great valley (and therefore older in date), and which are from 50 to 250 feet in perpendicular height, consist in great part of loam, containing land, fluviatile and lacustrine shells of species still inhabiting the same country. These fossil shells, occurring in a deposit resembling the loess of the Rhine, are associated with the bones of the mastodon, elephant, tapir, mylodon, and other megatheroid animals; also a species of horse, ox, and other mammalia, most of them of extinct species. The *loam* rests at Vicksburg and other places on eocene or lower tertiary strata, which in their turn repose on cretaceous rocks. A section from Vicksburg to Darier, through the States of Mis-

sissippi, Alabama and Georgia, exhibits this superposition as well as that of the cretaceous strata on carboniferous rocks at Tuscaloosa. Mr. Lyell ascertained that the huge fossil cetacean, named Zeuglodon by Owen, is confined to the eocene deposits. In the cretaceous strata the remains of the mosasaurus and other reptiles occur without any cetacea. The coal-fields of Alabama were next alluded to, from which fossil plants have been procured by Professor Brumby and Mr. Lyell, of the genera Sphenopteris, Neuropteris, Calamites, Lepidodendron, Sigillaria, Stigmaria and others, most of them identical in *species*, as determined by Mr. Charles Bunbury, with fossils of Northumberland. This fact is the more worthy of notice, because the coal of Tuscaloosa, situated in latitude 33° 10′ north, is further south than any region in which this ancient fossil flora had previously been studied, whether in Europe or North America; and it affords therefore a new proof of the wide extension of a uniform flora in the carboniferous epoch. Mr. Lyell, adverting to the opinion recently adopted by several able botanists, that the climate of the coal period was remarkable for its moisture, equability and freedom from cold, rather than the intensity of its tropical heat, stated that this conclusion, as well as the oscillations of temperature implied by the glacial period, is confirmatory of the theory first advanced by him in 1830, to explain the ancient geological changes of climate by geographical revolutions in the position of land and sea.

The lapse of ages implied by the distinctness of the fossils of the eocene, cretaceous, carboniferous and other strata, is such, that were we to endeavour to give an idea of it, we must estimate its duration, not by years, as in the case of the delta, but by such units as would be constituted by the interval between the beginning of the delta and our own times.

"It is now fifty years," said Mr. Lyell, "since Playfair, after studying the rocks in the neighbourhood of Edinburgh, in company with Dr. Hutton and Sir James Hall, was so struck with the evidence they afforded of the immensity of past time, that he observed 'how much farther reason may go than imagination can venture to follow.' These views were common to the most illustrious of his contemporaries, and since that time have been adopted by all geologists, whether their minds have been formed by the literature of France or of Germany, of Italy or Scandinavia, or of England; all have arrived at the same conclusion respecting the great antiquity of the globe, and that too in opposition to their earlier prepossessions, and to the popular belief of their age. It must be confessed, that while this unanimity is satisfactory as a remarkable test of truth, it is somewhat melancholy to reflect that at the end of half a century, when so many millions have passed through our schools and colleges since Playfair wrote that eloquent passage, there is still so great a discordance between the opinions of scientific men and the great mass of the community. Had there been annual gatherings such as this, where they who are entitled to speak with authority address themselves to a numerous assembly drawn from the higher classes of society, who, by their cultivation and influence, must direct the education and form the opinions of the many of humbler station, it is impossible that so undesirable and unsound a state of things should have now prevailed, as that there should be one creed for the philosopher and another for the multitude. Had there been meetings like this, even for a quarter of a century, we should already have gained for geology the same victory that has been so triumphantly won by the astronomer. The earth's antiquity, together with the history of successive races of organic beings, would have been ere this as cheerfully and universally acknowledged as the earth's motion, or the number, magnitude and relative distances of the heavenly bodies. I am sure it would be superfluous if I were to declare, in an assembly like this, my deep conviction, which all of you share, that the further we extend our researches into the wonders of creation in time and space, the more do we exalt, refine and elevate our conceptions of the Divine Artificer of the universe."

Mr. Lyell concluded this discourse by announcing his corroboration of the discovery recently made by Dr. King at Greensburg, thirty miles from Pittsburg in Pennsylvania, of the occurrence of fossil foot-prints of a large reptilian in the middle of the ancient coal measures. They project in relief from the lower surface of slabs of sandstone, and are also found impressed on the subjacent layers of fine unctuous clay. This is the first well-established example of a vertebrated animal, more highly organized than fishes, being met with in a stratum of such high antiquity.

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PROCEEDINGS OF THE FIFTH MEETING, at Dublin, 1835, 9*s*.

CONTENTS:—Rev. W. Whewell, on the Recent Progress and present Condition of the Mathematical Theories of Electricity, Magnetism, and Heat;—M. A. Quetelet, Aperçu de l'Etat actuel des Sciences Mathématiques chez les Belges;—Captain Edward Sabine, on the Phænomena of Terrestrial Magnetism.

Together with the Transactions of the Sections, Prof. Sir W. Hamilton's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE SIXTH MEETING, at Bristol, 1836, 8*s*.

CONTENTS:—Prof. Daubeny, on the Present State of our Knowledge with respect to Mineral and Thermal Waters;—Major Edward Sabine, on the Direction and Intensity of the Terrestrial Magnetic Force in Scotland;—Mr. John Richardson, on North American Zoology;—Rev. J. Challis, on the Mathematical Theory of Fluids;—Mr. J. T. Mackay, a Comparative View of the more remarkable Plants which characterize the neighbourhood of Dublin and Edinburgh, and the South-west of Scotland, &c.;—Mr. J. T. Mackay, Comparative Geographical Notices of the more remarkable Plants which characterize Scotland and Ireland;—Report of the London Sub-Committee of the Medical Section on the Motions and Sounds of the Heart;—Second Report of the Dublin Sub-Committee on the Motions and Sounds of the Heart;—Report of the Dublin Committee on the Pathology of the Brain and Nervous System;—J. W. Lubbock, Esq., Account of the Recent Discussions of Observations of the Tides;—Rev. Baden Powell, on determining the Refractive Indices for the Standard Rays of the Solar Spectrum in various media;—Dr. Hodgkin, on the Communication between the Arteries and Absorbents;—Prof. Phillips, Report of Experiments on Subterranean Temperature;—Prof. Hamilton, on the Validity of a Method recently proposed by George B. Jerrard, Esq., for Transforming and Resolving Equations of Elevated Degrees.

Together with the Transactions of the Sections, Prof. Daubeny's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE SEVENTH MEETING, at Liverpool, 1837, 11*s*.

CONTENTS:—Major Edward Sabine, on the Variations of the Magnetic Intensity observed at different points of the Earth's Surface;—Rev. William Taylor, on the various modes of Printing for the use of the blind;—J. W. Lubbock, Esq., on the Discussions of Observations of the Tides which have been obtained by means of the grant of money which was placed at the disposal of the Author for that purpose at the last Meeting of the Association;—Prof. Thomas Thomson, on the Difference between the Composition of Cast Iron produced by the Cold and Hot Blast;—Rev. T. R. Robinson, on the Determination of the Constant of Nutation by the Greenwich Observations, made as commanded by the British Association;—Robert Were Fox, Esq., Experiments on the Electricity of Metallic Veins, and the Temperature of Mines;—Provisional Report of the Committee of the Medical Section of the British Association, appointed to investigate the Composition of Secretions, and the organs producing them;—Dr. G. O. Rees, Report from the Committee for inquiring into the Analysis of the Glands, &c. of the Human Body;—Second Report of the London Sub-Committee of the British Association Medical Section, on the Motions and Sounds of the Heart;—Prof. Johnston, on the Present State of our knowledge in regard to Dimorphous Bodies;—Col. Sykes, on the Statistics of the Four Collectorates of Dukhun, under the British Government;—Eaton Hodgkinson, Esq., on the relative Strength and other Mechanical Properties of Iron obtained from the Hot and Cold Blast;—William Fairbairn, Esq., on the Strength and other Properties of Iron obtained from the Hot and Cold Blast;—Sir John Robison, and John Scott Russell, Esq., Report of the Committee on Waves, appointed by the British Association at Bristol in 1836;—Note by Major Sabine, being an Appendix to his Report on the Variations of the Magnetic Intensity observed at different Points of the Earth's Surface;—James Yates, on the Growth of Plants under glass, and without any free communication with the outward Air, on the Plan of Mr. N. J. Ward, of London.

Together with the Transactions of the Sections, Prof. Traill's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE EIGHTH MEETING, at Newcastle, 1838, 10*s*.

CONTENTS:—Rev. W. Whewell, Account of a Level Line, measured from the Bristol Channel to the English Channel, by Mr. Bunt;—Report on the Discussions of Tides, prepared under the direction of the Rev. W. Whewell;—W. Snow Harris, Esq., Account of the Progress and State of the Meteorological Observations at Plymouth;—Major Edward Sabine, on the Magnetic Isoclinal and Isodynamic Lines in the British Islands;—D. Lardner, LL.D., on the Determination of the Mean Numerical Values of Railway Constants;—R. Mallet, Esq., First Report upon Experiments upon the Action of Sea and River Water upon Cast and Wrought

Iron;—R. Mallet, Esq., on the Action of a Heat of 212° Fahr., when long continued, on Inorganic and Organic Substances.

Together with the Transactions of the Sections, Mr. Murchison's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE NINTH MEETING, at Birmingham, 1839, 9*s*.

CONTENTS:—Rev. Baden Powell, Report on the Present State of our Knowledge of Refractive Indices, for the Standard Rays of the Solar Spectrum in different media;—Report on the Application of the Sum assigned for Tide Circulations to Mr. Whewell, in a Letter from T. G. Bunt, Esq.;—H. L. Pattinson, Esq., on some galvanic Experiments to determine the Existence or Non-Existence of Electrical Currents among Stratified Rocks, particularly those of the Mountain Limestone formation, constituting the Lead Measures of Alston Moor;—Sir David Brewster, Reports respecting the two series of Hourly Meteorological Observations kept in Scotland at the expense of the British Association;—Report on the subject of a series of Resolutions adopted by the British Association at their Meeting in August 1838, at Newcastle;—Richard Owen, Esq., Report on British Fossil Reptiles;—Edward Forbes, Esq., Report on the Distribution of pulmoniferous Mollusca in the British Isles;—W. Snow Harris, Esq., Third Report on the Progress of the Hourly Meteorological Register at the Plymouth Dockyard, Devonport.

Together with the Transactions of the Sections, Rev. W. Vernon Harcourt's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TENTH MEETING, at Glasgow, 1840, 10*s*.

CONTENTS:—Rev. Baden Powell, Report on the recent Progress of discovery relative to Radiant Heat, supplementary to a former Report on the same subject inserted in the first volume of the Reports of the British Association for the Advancement of Science;—James D. Forbes, Esq., Supplementary Report on Meteorology;—W. Snow Harris, Esq., Report on Professor Whewell's Anemometer, now in operation at Plymouth;—Report on "The Motions and Sounds of the Heart," by the London Committee of the British Association, for 1839–40;—Professor Schönbein, an Account of Researches in Electro-Chemistry;—Robert Mallet, Esq., Second Report upon the Action of Air and Water, whether fresh or salt, clear or foul, and at various temperatures, upon Cast Iron, Wrought Iron, and Steel;—Robert Were Fox, Esq., Report on some Observations on Subterranean Temperature;—A. Follett Osler, Esq., Report on the Observations recorded during the years 1837, 1838, 1839 and 1840, by the Self-registering Anemometer erected at the Philosophical Institution, Birmingham;—Sir David Brewster, Report respecting the two Series of Hourly Meteorological Observations kept at Inverness and Kingussie, at the expense of the British Association, from Nov. 1st, 1838 to Nov. 1st, 1839;—William Thompson, Esq., Report on the Fauna of Ireland: Div. *Vertebrata*;—Charles J. B. Williams, M.D., Report of Experiments on the Physiology of the Lungs and Air-Tubes;—Rev. J. S. Henslow, Report of the Committee appointed to try Experiments on the Preservation of Animal and Vegetable Substances.

Together with the Transactions of the Sections, Mr. Murchison and Major Edward Sabine's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE ELEVENTH MEETING, at Plymouth, 1841, 9*s*.

CONTENTS:—Rev. Philip Kelland, on the Present State of our Theoretical and Experimental Knowledge of the Laws of Conduction of Heat;—G. L. Roupell, M.D., Report on Poisons;—Mr. Bunt, Report on Discussions of Bristol Tides, under the direction of the Rev. W. Whewell;—D. Ross, Report on the Discussions of Leith Tide Observations, under the direction of the Rev. W. Whewell;—W. S. Harris, Esq., upon the working of Whewell's Anemometer at Plymouth during the past year;—Report of a Committee appointed for the purpose of superintending the scientific co-operation of the British Association in the system of Simultaneous Observations in Terrestrial Magnetism and Meteorology;—Reports of Committees appointed to provide Meteorological Instruments for the use of M. Agassiz and Mr. M'Cord;—Report of a Committee to superintend the reduction of Meteorological Observations;—Report of a Committee for revising the Nomenclature of the Stars;—Report of a Committee for obtaining Instruments and Registers to record Shocks of Earthquakes in Scotland and Ireland;—Report of a Committee for making experiments on the Preservation of Vegetative Powers in Seeds;—Dr. Hodgkin, on Inquiries into the Races of Man;—Report of the Committee appointed to report how far the Desiderata in our knowledge of the Condition of the Upper Strata of the Atmosphere may be supplied by means of Ascents in Balloons or otherwise, to ascertain the probable expense of such Experiments, and to draw up Directions for Observers in such circumstances;—Richard Owen, Esq., Report on British Fossil Reptiles;—Reports on the Determination of the Mean Value of Railway Constants;—Dionysius Lardner, LL.D., Second and concluding Report on the Determination of the Mean Value of Railway

Constants;—Edward Woods, Report on Railway Constants;—Report of a Committee on the Construction of a Constant Indicator for Steam-Engines.

Together with the Transactions of the Sections, Prof. Whewell's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE TWELFTH MEETING, at Manchester, 1842, 7*s*.

CONTENTS:—Report of the Committee appointed to conduct the co-operation of the British Association in the System of Simultaneous Magnetical and Meteorological Observations;—John Richardson, M.D., Report on the present State of the Ichthyology of New Zealand;—W. Snow Harris, Report on the Progress of Meteorological Observations at Plymouth;—Second Report of a Committee appointed to make Experiments on the Growth and Vitality of Seeds;—C. Vignolles, Esq., Report of the Committee on Railway Sections;—Report of the Committee for the Preservation of Animal and Vegetable Substances;—Lyon Playfair, M.D., Abstract of Professor Liebig's Report on "Organic Chemistry applied to Physiology and Pathology;"—Richard Owen, Esq., Report on the British Fossil Mammalia, Part I.;—Robert Hunt, Researches on the Influence of Light on the Germination of Seeds and the Growth of Plants;—Louis Agassiz, Report on the Fossil Fishes of the Devonian System or Old Red Sandstone;—William Fairbairn, Esq., Appendix to a Report on the Strength and other Properties of Cast Iron obtained from the Hot and Cold Blast;—David Milne, Esq., Report of the Committee appointed at the Meeting of the British Association held at Plymouth in 1841, for registering Shocks of Earthquakes in Great Britain;—Report of a Committee appointed at the Tenth Meeting of the Association for the Construction of a Constant Indicator for Steam-Engines, and for the determination of the Velocity of the Piston of the Self-acting Engine at different periods of the Stroke;—J. S. Russell, Report of a Committee on the Form of Ships;—Report of a Committee appointed "to consider of the rules by which the Nomenclature of Zoology may be established on a uniform and permanent basis";—Report of a Committee on the Vital Statistics of large Towns in Scotland;—Provisional Reports, and Notices of Progress in Special Researches entrusted to Committees and Individuals.

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CONTENTS:—Robert Mallet, Esq., Third Report upon the Action of Air and Water, whether fresh or salt, clear or foul, and of Various Temperatures, upon Cast Iron, Wrought Iron and Steel;—Report of the Committee appointed to conduct the co-operation of the British Association in the System of Simultaneous Magnetical and Meteorological Observations;—Sir J. F. W. Herschel, Bart., Report of the Committee appointed for the Reduction of Meteorological Observations;—Report of the Committee appointed for Experiments on Steam-engines;—Report of the Committee appointed to continue their Experiments on the Vitality of Seeds;—J. S. Russell, Esq., Report of a Series of Observations on the Tides of the Frith of Forth and the East Coast of Scotland;—J. S. Russell, Esq., Notice of a Report of the Committee on the Form of Ships;—J. Blake, Esq., Report on the Physiological Action of Medicines;—Report of the Committee appointed to print and circulate a Report on Zoological Nomenclature;—Report of the Committee appointed in 1842, for Registering the Shocks of Earthquakes, and making such Meteorological Observations as may appear to them desirable;—Report of the Committee for conducting Experiments with Captive Balloons;—Professor Wheatstone, Appendix to the Report;—Report of the Committee for the Translation and Publication of Foreign Scientific Memoirs;—C. W. Peach, on the Habits of the Marine Testacea;—Edward Forbes, Esq., Report on the Mollusca and Radiata of the Ægean Sea, and on their distribution, considered as bearing on Geology;—M. Agassiz, Synoptical Table of British Fossil Fishes, arranged in the order of the Geological Formations;—Richard Owen, Esq., Report on the British Fossil Mammalia, Part II.;—E. W. Binney, Report on the excavation made at the junction of the Lower New Red Sandstone with the Coal Measures at Collyhurst, near Manchester;—W. Thompson, Esq., Report on the Fauna of Ireland: Div. *Invertebrata*;—Provisional Reports, and Notices of Progress in Special Researches entrusted to Committees and Individuals.

Together with the Transactions of the Sections, Earl of Rosse's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FOURTEENTH MEETING, at York, 1844, 13*s*. 4*d*.

CONTENTS:—W. B. Carpenter, M.D., F.R.S., on the Microscopic Structure of Shells;—Joshua Alder and Albany Hancock, Report on the British Nudibranchiate Mollusca;—Robert Hunt,

Researches on the Influence of Light on the Germination of Seeds and the Growth of Plants; —Report of a Committee appointed by the British Association in 1840, for revising the Nomenclature of the Stars;—Lieut.-Colonel Edward Sabine, R.A., F.R.S., on the Meteorology of Toronto in Canada;—John Blackwall, F.L.S., Report into some recent researches into the Structure, Functions and Œconomy of the *Araneidea* made in Great Britain;—the Earl of Rosse, on the Construction of large Reflecting Telescopes;—the Rev. William Vernon Harcourt, F.R.S., Report on a Gas Furnace for Experiments on Vitrifaction and other Applications of High Heat in the Laboratory;—Report of the Committee for Registering Earthquake Shocks in Scotland;—Report of a Committee appointed at the Tenth Meeting of the Association for Experiments on Steam-Engines;—Report of the Committee to investigate the Varieties of the Human Race;—Fourth Report of a Committee appointed to continue their Experiments on the Vitality of Seeds;—William Fairbairn, Esq., on the Consumption of Fuel and the prevention of Smoke;—Francis Ronalds, Esq., F.R.S., Report concerning the Observatory of the British Association at Kew;—Sixth Report of the Committee appointed to conduct the Co-operation of the British Association in the System of Simultaneous Magnetical and Meteorological Observations;—Prof. Forchhammer, on the influence of Fucoidal Plants upon the Formations of the Earth, on Metamorphism in general, and particularly the Metamorphosis of the Scandinavian Alum Slate;—H. E. Strickland, M.A., F.G.S., Report on the recent Progress and present State of Ornithology;—T. Oldham, Esq., M.R.I.A., Report of Committee appointed to conduct Observations on Subterranean Temperature in Ireland;—Prof. Owen, F.R.S., Report on the Extinct Mammals of Australia, with descriptions of certain Fossils indicative of the former existence in that Continent of large Marsupial Representatives of the Order Pachydermata;—W. Snow Harris, Esq., F.R.S., Report on the working of Whewell and Osler's Anemometers at Plymouth, for the years 1841, 1842, 1843;—W. R. Birt, Report on Atmospheric Waves;—L. Agassiz, Rapport sur les Poissons Fossiles de l'Argile de Londres, with translation;—J. Scott Russell, Esq., M.A., F.R.S.E., Report on Waves;—Provisional Reports, and Notices of Progress in Special Researches entrusted to Committees and Individuals.

Together with the Transactions of the Sections, Dean of Ely's Address, and Recommendations of the Association and its Committees.

PROCEEDINGS OF THE FIFTEENTH MEETING, at Cambridge, 1845, 8s.

CONTENTS.—Seventh Report of the Committee appointed to conduct the co-operation of the British Association in the System of Simultaneous Magnetical and Meteorological Observations;—Lieut.-Col. Sabine, on some points in the Meteorology of Bombay;—J. Blake, M.B., Report on the Physiological Action of Medicines;—Dr. Von Boguslawski, on the comet of 1843;—R. Hunt, Esq., Report on the Actinograph;—Prof. Schönbein, on Ozone;—Prof. Erman, on the influence of friction upon Thermo Electricity;—Baron Senftenberg, on the Self-Registering Meteorological Instruments employed in the Observatory at Senftenberg;—W. R. Birt, Esq., Second Report on Atmospheric Waves;—G. R. Porter, Esq., on the Progress and Present Extent of Savings' Banks in the United-Kingdom;—Prof. Bunsen, and Dr. Playfair, Report on the Gases evolved from Iron Furnaces, with reference to the theory of Smelting of Iron;—Dr. Richardson, Report on the Ichthyology of the Seas of China and Japan;—Report of the Committee on the Registration of Periodical Phænomena of Animals and Vegetables;—Fifth Report of the Committee on the Vitality of Seeds;—Appendix, &c.

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